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Distinguishing Appraisals of Memory Accuracy and Occurrence: A Functional Neuroimaging Study

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By

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ABSTRACT

The ability to remember has been described as one of the most important cognitive functions, largely because it is evolutionarily optimal to be able to retain information relevant to survival. Autobiographical memory, which is defined as one's memory for their own experiences, is especially paramount as it contributes to self-identity and the ability to learn from past experiences. The current study investigated the brain activation associated with different types of social feedback on autobiographical memory through the use of Functional Near-Infrared Spectroscopy (fNIRS). Seventeen undergraduate participants were presented with video- and audio-recorded scenes of an actress performing everyday tasks. One week later, they were given either confirmatory or disconfirmatory social feedback regarding the accuracy and occurrence of their memories whilst their left prefrontal cortical brain activity was recorded using fNIRS. It was found that on average, participants' brain activity differed dependent upon whether the feedback was about scene details or scene occurrence, and upon whether the feedback was confirmatory or disconfirmatory. It was also found that participants who maintained, relinquished, or partially relinquished their belief in their memory had distinct patterns of cortical activity. This study was the first to use a functional neuroimaging paradigm to investigate the dissociation between one's appraisals of belief in accuracy and occurrence, demonstrating that they are neurologically distinct metamemorial appraisals. Thus, these findings reinforce the uniqueness of decision-making about memory in general, highlighting the continued need for research investigating the appraisals contributing to memory reports.

DEDICATION

This thesis is dedicated to Dr. Alan Scoboria, whose immense passion for research and academia continues to inspire and drive so many today. Throughout his battle with brain cancer, he chose to continue to supervise and mentor students, to read and edit manuscripts, and to talk enthusiastically about his research interests with anyone who reached out to him. I am forever grateful to have been one of his students and to have had such a fantastic mentor who believed in me even when I didn't believe in myself. He has truly helped to shape who I am today, not only as a researcher, but as a person. Thank you Dr. Scoboria, I hope that this thesis would have been "sufficient" or even "100000000% better; EOM" than the last two.

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CHAPTER 1

Introduction

Linking the Past to the Future through Memory

Remembering is described by Bartlett (1932) as a reconstruction of our own imagination, stemming from the relationship between our attitudes and our organized past experiences. The ability to remember allows us to essentially "re-experience" events that may or may not be pertinent to our life stories. For example, most people can look fondly upon the memory of their high school graduation, or their first time riding a bike. However, there are instances in which remembering can be disrupted, disjointed, or otherwise departed. In the classic case of Henry Molaison (famously known as HM), the removal of the hippocampi within his medial temporal lobes resulted in a devastating condition known as *anterograde amnesia*, which is the inability to form new memories (Scoville & Milner, 1957). Any type of memory loss can be especially calamitous because evolutionarily, our memory systems have been optimized to process and retain fitness-relevant information, which allows us the ability to make decisions that can benefit us in the future (Nairne & Pandeirada, 2016). For these reasons, memories are much like "time capsules", used to recount the past and to teach lessons for the future (Rubin, 1988). In other words, by remembering the things that have happened to us, we subsequently shape our future thoughts, goals, and actions.

The Basic Systems Model of Memory (Rubin, 2006) suggests that the mind and brain are separated into several basic systems, and that separate systems for each of the senses, spatial imagery, language, emotion, narrative, and motor output exist. Rubin (2006) postulates that these systems all have their own forms of memory, and that

multiple different metamemory processes are used to assemble one's experience of remembering. In this model, two specific appraisals are discussed and have been established as being important for remembering what has happened in the past: *belief*, which refers to the degree to which one's perception of an event corresponds to the way that it was truly experienced, and *recollection*, which is described as the presence of a vivid mental representation, including a sense of re-experiencing of an event. Recollection and belief are considered to be important metacognitive judgements based on their high level of processing in each of the basic systems (spatial imagery, language, emotion, narrative, and motor output).

Autobiographical Remembering

One important form of memory is *autobiographical memory*, which refers to the memories that a person has of their own life experiences (Rubin, 1988). This type of memory plays a fundamental role in the development and maintenance of one's self concept because it helps define who we are, and it ties us to our own personal histories (Sheen, Kemp, & Rubin, 2001). The language used to describe this form of memory has been widely disputed and it has past been referred to with terms such as "suddenly remembering" (Munsat, 1967), and "personal memory" (Locke, 1971). The meaning of the term "autobiographical memory" has been quite controversial, with some referring to it as a form of episodic memory (Kopelman & Kapur, 2001; Rubin, 1998) and others placing more emphasis on the importance of retaining knowledge about oneself to pursue and achieve personal goals (Conway & Pleydell-Pierce, 2000).

Brewer (1986; 1995) prefers to use the term *recollective memories*, which he describes as memories that occur when an individual recalls any specific episode from

their own past. Brewer (1986) organizes recollective memories into four autobiographical groups based on their acquisition conditions (single instance or repeated instance) and their form of representation (imaginal or non-imaginal). First, a *personal memory*, is a phenomenally experienced (i.e., perceptible by use of the senses or through immediate experience) product of a single episode (e.g., I went rollerblading at Lakewood park on Tuesday). Second, an *autobiographical fact*, is a non-phenomenally experienced product of a single episode (e.g., I can recall *that* I went rollerblading on Tuesday). Third, a *generic personal memory*, is a phenomenally experienced product of multiple episodes (e.g., I have an image of myself rollerblading in an [unspecified] park in an [unspecified] area of town). Finally, one forms their *self-schema* using the non-phenomenally experienced product of multiple episodes (e.g. I am someone who likes to rollerblade).

Autobiographical memory includes a rich database of knowledge about oneself, which makes it difficult to pinpoint a precise definition for it (Holland & Kensinger, 2010). This is largely because of Tulving (1972; 1983) who suggests that autobiographical memory is divided into both episodic and semantic memory systems, encompassing personal semantic information (e.g., facts about oneself, such as knowing the date of your birthday), and personal episodic information (e.g., unique events, such as remembering your high school graduation). Interestingly, recalling personal semantic information does not depend on retrieving specific experiences, but rather is linked to feelings of familiarity. Personal episodic memory is recalled quite differently, requiring a sense of re-experiencing and the recollection of particular past events (Wheeler, Stuss, & Tulving, 1997).

Greenberg and Rubin (2003) also provide a comprehensive definition of autobiographical memory, postulating that the term refers to memories that have several properties: first, they state that autobiographical memory and episodic memory are similar because they both receive and store information that is temporally dated, and is about specific events that have a temporal-spatial relation among them (Tulving, 1983). Second, they highlight that autobiographical memories involve more than just the retrieval of stored data. As described by Tulving (1985), the rememberer must be conscious of their prior conscious experience, a phenomenon known as *autonoetic consciousness*. This autonoetic consciousness is a necessary but insufficient quality that contributes to a memory being categorized as an autobiographical memory. The accounts of philosophers (Brewer, 1995) and of amnesiacs (Crovitz, 1986) suggest that autobiographical memories should be accompanied by a belief that the event occurred, as well as experiences of reliving the event (Greenberg & Rubin, 2003). Therefore, according to Greenberg and Rubin (2003), a memory of a personally experienced event that stems from a sense of recollection or reliving is termed an autobiographical memory.

Memories can be Altered

There is a large body of research that suggests that memories are dynamic reconstructions of the past, making them susceptible to change (Neisser, 1996; Wright & Loftus, 1998). Because of this, the ability to remember things that have happened can be both a blessing and a curse. Memory allows us to remember the things that are most important, but it cannot always be trusted. *The misinformation effect* refers to an impairment in one's memory for the past that occurs when they have been exposed to misleading information (Loftus, 1975). A 30-year investigation of the malleability of

memory has addressed many of the questions surrounding this phenomenon (Loftus, 2005). First, we know that people are particularly prone to having their memories affected by misinformation if it is introduced after the passage of time (Loftus, Miller, & Burns, 1978). This is because it is possible that the memory has faded, and therefore it is less likely that a discrepancy will be noticed. Second, it has been demonstrated that the misinformation effect influences the memory of some people more than others. Individual factors such as age (Ceci & Bruck, 1993; Karpel, Hoyer, & Toglia, 2001; Davis & Loftus, 2005), and certain personality characteristics such as empathy (Wright & Livingston-Raper, 2002) play a prominent role in whether a person will fall prey to the misinformation effect.

The misinformation effect postulates that new information can be added to existing memories due to post-event influences. Loftus and Palmer (1974) presented their participants with videos of automobile accidents and they instructed them to answer questions such as “about how fast were the cars going when they *smashed* into each other?”. This particular question suggests that the cars must have been going quite fast, and when participants were administered a memory test one week later, the participants who were given the verb *smashed* (others were given words such as *bumped* or *collided*) were more likely to answer “yes” to the question “did you see any broken glass?” when there was in fact, no broken glass. In this experiment, the introduction of the word "smashed" provided the participants with new information that was then incorporated into the original memory for the scene. When this happens, the participant now has a memory for an event that was much more severe than the original accident,

demonstrating that new and/or false information can be introduced into a person's memory.

In another classic study, Loftus, Miller, and Burns (1978) found that information obtained after an event can do more than just supplement or add to your memory; it can alter it completely. Participants were again shown a series of slides depicting an automobile accident, this time involving a pedestrian. Immediately after viewing the slides, participants answered a series of questions. Half were asked "did another car pass the red Datsun while it was stopped at the *stop* sign?", and the other half were asked the same question about a *yield* sign. All participants then completed a memory test in which fifteen pairs of slides were presented and were asked to choose the slide that they had seen earlier. The most critical pair of slides showed the red Datsun coming to a stop at a stop sign, and an identical slide depicting the Datsun at a yield sign. The results of this study demonstrated that the misleading information (the intervening question described above) produced less accurate responding (e.g., participants were more likely to choose the option that the leading question had contained). These findings demonstrate that the information that a witness is exposed to after an event, whether it is consistent or misleading, can transform that witness' memory of the event.

Interestingly, Zaragoza and Lane (1994) took a different approach in their exploration of the misinformation effect. In their study, they were interested in determining whether people confuse their misleading suggestions for "real" memories of a witnessed event, or if they just accept what others have told them as being true without any personal recollection; a phenomenon known as the *source misattribution effect*. The results of this study ultimately provided strong evidence that subjects really do believe

that they remembered seeing suggested items (that were never actually presented to them). Following the work of Zaragoza and Lane, Hyman (1999) clarified the three cognitive processes required for the creation of these false memories: (1) acceptance of the suggested information/event as plausible, (2) the creation of related imagery or narrative, and (3) error(s) in source-monitoring. To elaborate, first, an event must be plausible for it to be accepted as a possible memory. Next, one must have formed an image or narrative of the event. And finally, a source monitoring error, where the individual fails to recognize the source of the memory, must be made. This means that a person may believe an event to be plausible but may not think the event is an actual memory. Hyman (1999) highlights that having clear images and a greater level of affect and self-involvement helps to increase the chance that a suggested or discounted memory will be deemed as legitimate.

In everyday life, this phenomenon can occur when individuals who experience an event together later discuss what happened to them. Wagenaar and Crombag (2005) introduced the term *collaborative storytelling*, which represents the mutual reinforcement of ideas, that can occur when people attempt to collaboratively judge uncertain information. They presented a legal case where they proposed that when eyewitnesses were asked about their memory for an event that could not be verified by direct observation, they would tend to base their uncertainty upon the judgements of others. The authors relate this finding to the aforementioned study by Loftus, Miller, and Burns (1978) whereby information that a witness is exposed to after an event gets incorporated into their memory for that event. According to Loftus and Hoffman (1989), this

misinformation acceptance leads to a high degree of conviction about the new memories, making it more believable.

This phenomenon has also been studied in university students. Hyman, Husband, and Billings (1995) were interested in determining whether university students create false memories of childhood experiences in response to misleading questions and the demands of an interview. In their first experiment, they provided their subjects with descriptions of events that had allegedly occurred during the students' childhood. They found that 20% of the students agreed that these events occurred, later freely recalling the event with the misinformation included in their rendition of the memory. A second experiment used less likely events such as spilling punch on the parents of the bride at a childhood wedding. This protocol also employed an extra interview, and increased conformity demands. The results indicated that 25% of the students produced a false recall. Taken together, this study illustrates that some individuals create false memories, and those who discuss related background knowledge during the early interviews are more likely to create a false recollection. The authors suggest that incorporation of information about remembered events in response to the social context may be a general phenomenon. In other words, when people engage in memory discussions with others, those around them may present differing views, memories, and reactions; calling into question their own memory for the event.

Although memory can be transformed due to post-event influences, there are instances in which people resist feedback from others. In one study, researchers examined "disputed memories", which differ from the memory errors previously described in that the major detail in dispute relates to who is protagonist of the event (Sheen, Kemp, &

Rubin, 2001). This was investigated in twins who disagreed about who 'owns' a certain autobiographical memory. For example, one disputed memory was described as "I (not my sister) ran into a clothesline and cut my head". It was determined that disputed memories are a stable and reliable memory error, and that they occur frequently among twins who spend a great deal of time together. Moreover, the twins in this study were unwilling to give up their autobiographical memories and considered them to be true accounts of past experiences even when they were presented with contrary evidence from the other twin. In this case, the dissonance (i.e., mental discomfort) that results from receiving discordant information from a trusted individual is relieved because of the unwillingness to relinquish the memory.

Cognitive Dissonance

Festinger (1957) proposed that humans strive for internal psychological consistency because it allows us to function well mentally. When people receive information that is inconsistent or discordant from what they believe to be true, cognitive discomfort, or dissonance, is experienced. Dissonance may arise from within a social group when an individual's memory for an event is challenged by another person. Festinger (1957) examined how holding thoughts that are inconsistent with one another creates a "mental discomfort" that causes us to act in order to relieve this discomfort. He suggests that we may resolve this discomfort caused by holding inconsistencies in one of three ways: (a) by changing one of the discordant thoughts/beliefs, (b) by changing the behavior that is related to the inconsistency, or (c) by adding new thoughts which allow us to rationalize the inconsistency. For example, drinking alcohol is something that many people enjoy doing, but also know that it is bad for their health. In order to reduce the

cognitive dissonance that arises from these conflicting thoughts, one must resolve the inconsistencies. This can be done as Festinger (1957) suggests, by changing one of the thoughts/beliefs. One may think "alcohol isn't *that* bad for you", which would change one of the cognitions as a way of restoring consistency. Cognitive dissonance could also be reduced by changing the behaviour that is related to the inconsistency, by refusing to consume the alcoholic beverages, or consuming alcohol only once in a while. Finally, one could also add a thought, such as "alcohol is bad for you, but I exercise and eat healthy so it's okay", allowing them to rationalize the inconsistency.

In a recent study by Korcsog et al. (In Preparation), it was found that when receiving social feedback about actions performed in the lab, disconfirmatory feedback elicits cognitive dissonance. Undergraduate students were asked to either perform, imagine, or listen to a prompt for a series of 120 actions. One week later, the students rated their belief in the occurrence, vividness, and visual experience of their memory for 90 actions. The researcher then gave feedback about the participant's memory for 12 actions, 6 of which were instances of disconfirmatory feedback (i.e., "You said performed, that is incorrect. You imagined this action." Or "You said imagined, that is incorrect. You heard this action."). It was found that the disagreement between the researcher and the participant on the source of an event elicits cognitive dissonance in the participant. This cognitive dissonance was assessed using Matz and Wood's (2005) Emotion Measure, whereby a heightened score on questions asking if a person is feeling "uneasy", "uncomfortable", and "tense" represents dissonance discomfort. Van Veen and colleagues (2009) have shown using fMRI that when experiencing cognitive dissonance, the dorsal anterior cingulate cortex and anterior insula of the brain are active. The

magnitude of the activation of these two structures in turn predicts the subsequent attitude change.

A Social-Cognitive Model of Memory

This brings into question the distinct underlying social-cognitive processes that come into play when receiving feedback about memory. Scoboria and Henkel (2020) outline a social-cognitive model of memory, the SCOboria Social-Cognitive Dissonance Model of Challenges to Memory, which explains the processing of cognitive dissonance that results when a person is told that their vivid memory did not actually occur in the past. This model posits that when we receive social feedback that invalidates the occurrence of remembered events, both intrapersonal and interpersonal cognitive dissonance results. When processing intrapersonal cognitive dissonance, we tend to weigh our own memory representation against the qualities of the feedback that has been given (such as whether the feedback is plausible). When processing interpersonal cognitive dissonance, we tend to weigh the potential costs and benefits of agreeing or disagreeing with the feedback provider (e.g., will disagreeing with this person negatively affect the relationship?). We are most often motivated to resolve both forms of dissonance. Scoboria and Henkel (2020) suggest that in order to resolve dissonance, one must evaluate the original memory, evaluate the social feedback, and then weigh the potential costs and benefits of responding in the context of the relationship. Only then can we either choose to maintain or reduce our belief in the occurrence of the event, and choose to agree with, disagree with, or to not communicate this decision about belief in occurrence to the challenger. Four outcomes may arise from this model: compliance, event denial, event relinquishment, and memory defense (see Figure 1).

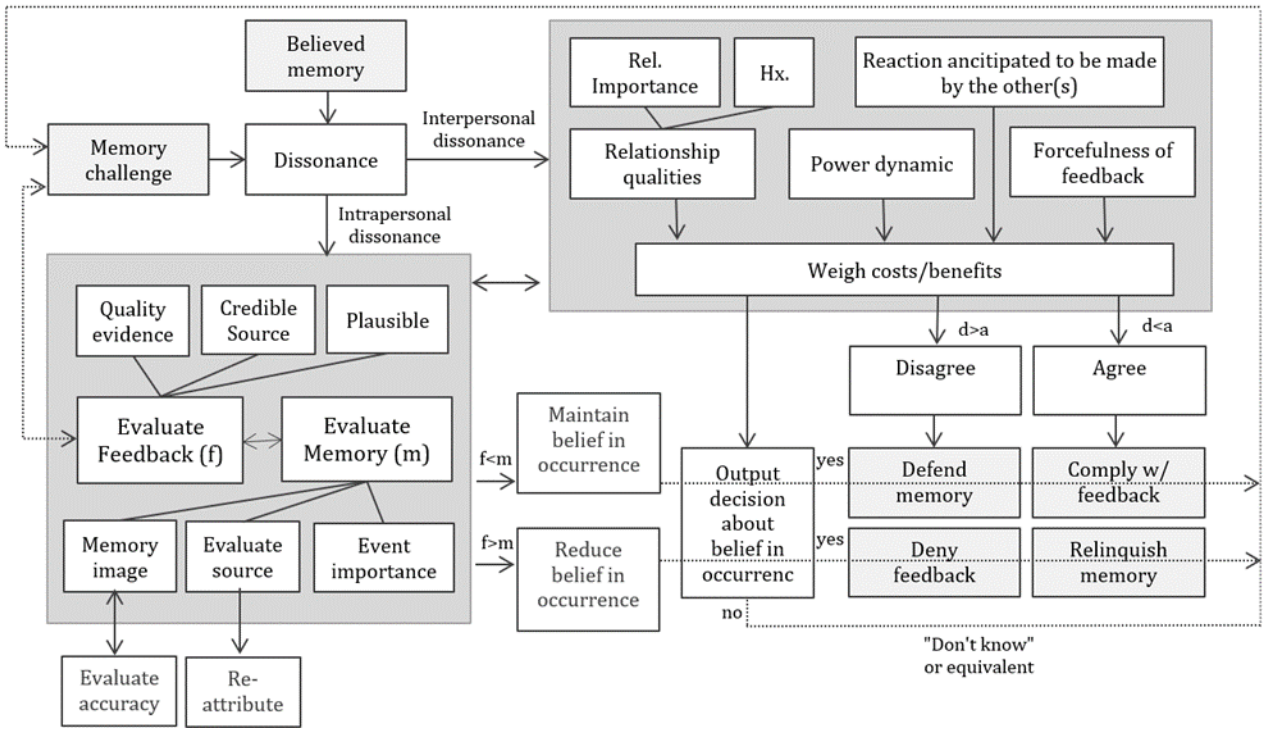

Figure 1. Scoboria and Henkel's (2020) social-cognitive model of memory. When an individual receives social feedback from a challenger that a memory that they currently believe to be true did not occur, this results in 1) intrapersonal dissonance and 2) interpersonal dissonance. Intrapersonal dissonance is processed by evaluating the qualities of the feedback against the qualities of the memory, resulting in the decision to maintain or decrease belief in occurrence for the event. Interpersonal dissonance is processed by evaluating the costs and benefits of agreeing or disagreeing with the other person about the memory. Crossing these dimensions results in four possible outcomes for the memory (bottom right).

Belief in Occurrence

When an event is remembered, the re-perception or *recollection* is not the only mental experience that occurs; the event is usually believed to have truly occurred in the

past. It is important to note however, that the presence of a recollection does not always mean that belief in the event exists (Scoboria et al., 2014). The term *belief in occurrence* (or *autobiographical belief*) is defined as the level of truth attributed to the occurrence of an event, whether or not that event is truly recollected (Mazzoni, Scoboria, & Harvey, 2010; Scoboria et al., 2004). Scoboria et al. (2004) postulate that plausibility, belief, and memory are nested constructs that are related to the perceived occurrence of an autobiographical event. This is because, in most cases, if a person remembers an event, they believe that it truly occurred in the past, and it will be regarded as plausible. For example, research looking at false confessions conducted by Gudjonsson (2003), asserts that when people confess to crimes that they did not actually commit, the first step in confessing is determining that they could have plausibly committed the crime.

Sometimes people report vivid memories that they still recollect, but no longer believe occurred to them; these memories are known as *nonbelieved memories.* Mazzoni, Scoboria, and Harvey (2010) conducted the first empirical study of nonbelieved memories, finding that approximately 20% of their sample reported having at least one nonbelieved memory and that nonbelieved memories share many of the recollective qualities that believed memories do. A recent study by Otgaar and colleagues (2019) examined The False Memory Archive, a unique art collection that contains hundreds of false memory reports, and found that of 500 submissions, 53.4% were nonbelieved memories. According to Mazzoni, Scoboria, and Harvey (2010), one characteristic that is uniquely associated with nonbelieved memories is the surprising intensity of negative emotions. The authors suggest that this may be due to the nature of the remembered event, or to the negative feelings surrounding the relinquishment of the memory. They

also note that nonbelieved memories seem to be less personal and less connected to one's self-concept than memories for events that have never been doubted, likely due to having less personal significance.

Belief in Accuracy

The term *belief in accuracy* refers to the degree to which an event is believed to have occurred in the way it was recalled; that the details that come to mind correspond to the details that were present when the event was experienced (Scoboria, Talarico, & Pascal, 2015). As we now know, one characteristic of autobiographical memory is that it can often be influenced by social input from others, and that our memory for the details of an event can become quite fuzzy (Echterhoff & Hirst, 2009). It has been demonstrated that when participants discuss past events with a confederate, they are much more likely to incorporate the confederate's recollection of the details of an event into their own memory (Merckelbach, van Roermund, & Candel, 2006). Studies also show that it is more likely that an incorrect detail will be implanted than it is to remove a correct detail (Loftus, Levidow, and Duensing, 1992). This is because attempting to remove a correct detail from someone's memory requires misinformation that would contradict their prior recollections. Inserting an incorrect detail can be done with misinformation that is consistent with the scene itself, making it more plausible that the person could have just missed that detail during the original encoding of the event in question.

Misinformation that stems from when a participant is accompanied by a confederate can erase certain details from within memory reports (Wright et al., 2001; Gabbert et al., 2006). The person may also decide to withhold the reporting of certain details that they remember if the confederate pronounces a different account of an event,

due to the social pressure of the situation. This subsequently allows the feedback that has been given by the confederate to affect their memory for the details of the event. Gabbert et al. (2006) and Wright et al. (2001) both agree that when one is recounting the details of a scene by free-recall and another person suggests erroneous details and/or denies correct details, this seems to be able to alter memory reports in a similar way.

Distinguishing Subtypes of Metamemory Beliefs

Brewer (1996) defines autobiographical remembering as being comprised of multiple metamemorial components. First, he states that a memory image (recollection) must be present. Second, he states that one must believe that the event occurred in the past (autobiographical belief/belief in occurrence). Finally, one must possess confidence that the details recalled accurately represent what has occurred in the past (belief in accuracy). Belief in occurrence and belief in accuracy ratings are largely synonymous in the literature, this is because spontaneous generation and laboratory experiments will typically elicit memories for events that are vividly recollected, are believed to have occurred, and are viewed to be accurate (Scoboria & Talarico, 2013). Scoboria, Talarico, and Pascal (2015) describe this as being because research investigating belief in occurrence and belief in accuracy tend to elicit memories for which both co-occur at high levels.

In their investigation of the subtypes of nonbelieved memories, Scoboria, Nash, and Mazzoni (2017) discovered several types of memories that participants rated belief in accuracy and belief in occurrence similarly, including “weak nonbelieved memories” (manipulations that question the recollective qualities of the memories), “grain-of-doubt nonbelieved memories” (procedures undermining the objective plausibility of the

memory), and of course, believed memories. They discuss that the objective plausibility of events and social influence interact with other characteristics when determining the level of belief in accuracy for nonbelieved memories, which is why it may have been rated similarly to belief in occurrence in the "weak nonbelieved memories" and "grain-of-doubt nonbelieved memories" categories.

Belief in Accuracy and Belief in Occurrence are Distinct

It has recently been suggested that belief in occurrence, belief in accuracy, and recollection are theoretically distinct aspects of autobiographical remembering. In one study by Scoboria, Talarico, and Pascal (2015), it was newly established that belief in accuracy and belief in occurrence may be distinct metamemorial processes. The authors found that each emerged as a distinct latent variable in their confirmatory modelling process. This distinction suggests that it is possible to edit the details within a memory without altering the overarching autobiographical belief appraisals. Korcsog (2017) attempted to further investigate this distinction, using simple scenes of an actress performing everyday tasks (e.g., making a sandwich). With the goal of further demonstrating the distinction between belief in occurrence and belief in accuracy in a controlled experimental setting, the researchers provided participants with feedback about their memory that was either confirmatory or disconfirmatory towards memory accuracy and occurrence. When participants were given negative feedback about belief in occurrence and positive feedback about the accuracy of their recollection, a decrease in belief in occurrence ratings emerged and there was no change in belief in accuracy ratings, demonstrating a dissociation between the two metamemory appraisals.

As one of the first studies to attempt to separate these constructs experimentally, Korcsog's (2017) results elucidated an unexpected artifact whereby the feedback about belief in occurrence was targeting source monitoring rather than belief in occurrence. This was because, instead of telling the participant that they had not been presented with a scene (that they had in fact seen), they told participants that they had actually heard the scene (rather than having watched it as a video), creating source monitoring confusion between visual and auditory stimuli. Recently, this flaw has been addressed and corrected. Korcsog et al. (In Preparation) found that when participants receive disconfirmatory feedback about scene occurrence ("you were incorrect in saying that a scene of a girl __ was presented in session 1"), belief in accuracy and belief in occurrence scores both decrease. When participants receive disconfirmatory feedback about the accuracy of their memory for scenes ("you remembered less than 50% of the details correctly"), belief in occurrence ratings remained the same, but belief in accuracy scores decreased. These findings demonstrate a partial dissociation between belief in occurrence and belief in accuracy, suggesting that they are nested constructs. It is suggested that belief in occurrence may act as an overarching construct, since in this experiment, having belief in the accuracy of memory depended on having belief in the occurrence of it.

Believing that you are accurate about your memory is often thought to go hand-in-hand with believing that the remembered event occurred, however as previously discussed, it has been shown that it is possible to possess a strong recollection of an event but not believe that the event occurred. Similarly, it is also possible to possess strong belief that a scene is recalled correctly in the absence of a belief that it occurred. For example, Scoboria, Nash, and Mazzoni (2017) isolated a cluster of Classic NBMs

(defined as having low belief ratings and high recollection ratings) in which belief in accuracy remained high, encompassing cases such as "borrowed memories". In these cases, a person recalls an event and can corroborate the details, yet also discovers that they had not truly been present and had instead learned the details from another person.

The phenomenon of borrowed memories was also studied by Korcsog (2018), in which the author endeavored to separate belief in accuracy ratings *from* belief in occurrence ratings. To do this, participants were provided with feedback about their memory for certain central details within scenes of an actress performing simple tasks (the same scenes as in Korcsog (2017) and as in the current study). This was done with the goal of isolating and affecting only the participant's belief in the accuracy appraisals of their memory (while not affecting their belief in occurrence appraisals of the scene). What was found was that when participants received disconfirmatory feedback about the accuracy of their memory, the change in accuracy ratings was significantly greater than their belief in occurrence ratings, again demonstrating a distinction between the two appraisals. This is not surprising considering that one can believe that certain aspects of their memory are incorrect, but can still believe that the memory occurred, similar to believed-not-remembered memories described by Mazzoni, Scoboria, and Harvey (2010).

Using a similar approach, Otgaar et al. (2018) examined the impact of social feedback and objective false evidence on participants' belief in occurrence, belief in accuracy, and recollection. In this study, participants underwent a virtual reality experience in which they were shown six different virtual reality scenes and were then given a memory test asking about belief in occurrence, belief in accuracy, and recollection for the experienced scenes. After a one-week delay, participants returned to

the lab and were either suggestively told that one of the events was not experienced, received objective false evidence that the event did not occur, a combination of both, or received nothing. The findings suggest that these manipulations predominantly decreased participants' belief in occurrence, demonstrating that belief in occurrence is more receptive to social demands than belief in accuracy or recollection, further distinguishing the three.

Autobiographical Memory in the Brain

Similar to investigations aimed at distinguishing memory processes using reports of past events, neuroscientists are also tasked with determining the form and function of brain structures involved in various memory processes. One of the most well-known findings in the area of neuroscience is that damage to the medial temporal lobes and hippocampus result in impaired memory processes (Scoville & Milner, 1957). This and subsequent studies lead to the understanding that episodic memories are neurologically dissociable from short-term and working memory (Moscovitch et al., 2016). Importantly, Jacobsen (1936) demonstrated that the prefrontal cortex also plays a significant role in working memory. In his study, the pre- and post-operative records of monkeys who had underwent bilateral and unilateral ablation of the prefrontal cortex were examined. He found that after bilateral ablation of the frontal association areas, the monkey would experience a permanent loss of capacity for working memory.

The prefrontal cortex is also proposed to be one of the major areas of the brain that are involved in specific components of autobiographical memory. Miller and Cohen (2001) describe the prefrontal cortex as being able to coordinate distributed brain activity to accomplish goals, since it is able to flexibly and dynamically implement domain-

general, top-down, cognitive control processes. Milner and Petridas (1984) investigated the effects of focal prefrontal cortical lesions on tests of long-term contextual memory and found that these lesions resulted in reduced output on fluency tasks, poor regulation of behaviour of external cues, impaired organization, poor monitoring of materials that were to be remembered, and decreased responses to stimuli.

In his work on the Basic Systems Model of Memory, Rubin (2006) described that when recalling autobiographical memories, several areas of the brain are active. He states that there is activity in the explicit memory system, referencing Addis et al. (2004) who found that when participants retrieve specific autobiographical memories, the associated activation is in regions involved in imagery in episodic memory such as the left precuneus, the left superior parietal lobule, and the right cuneus. Rubin (2006) then highlights the search-and-retrieval system, referencing Conway et al. (1999) who found that the left frontal cortex (as well as the left inferior temporal and occipital lobes) was active during the retrieval of autobiographical memories. They suggest that left frontal activation during the retrieval of autobiographical memories reflects the operation of control processes that are used to modulate the construction of autobiographical memories in the posterior neocortical pathways. Next, Rubin (2006) outlines the importance of the visual and spatial system in the recollection of autobiographical memories, referencing Addis et al., (2004) who state that specific autobiographical memories are composed of visual and contextual information, therefore rely on regions such as the precuneus and the parietal regions. Finally, Rubin (2006) highlights the emotion system as playing a role in memory, referring to the work of Greenberg et al. (2005) who found that the amygdala, hippocampus, and right inferior frontal gyrus was

active during autobiographical retrieval but not semantic retrieval of memory. This suggests that the emotional component of autobiographical memory is tied to these brain regions.

Svoboda, McKinnon, and Levine (2006) provide a comprehensive meta-analysis of studies investigating autobiographical memory in the brain. Existing theories of memory and the findings summarized in their article suggest that the left-prefrontal cortex plays a significant role in autobiographical remembering. They also highlight that in many of the studies that they reviewed, the hippocampus, amygdala, and the cerebellum are active when one is retrieving autobiographical memories. Another important finding was that there is a shift in lateralization (from left-hemisphere to mid-brain) of the autobiographical memory network caused by emotional events, whereby there is activation in emotion-centered regions (such as the amygdala) and deactivation in locations associated with cognitive processes (such as the frontal cortex).

Spreng and Grady (2010) investigated and compared the neural mechanisms underlying autobiographical memory, prospective memory, and theory of mind, demonstrating that the three share a common pattern of brain activity. Using fMRI, these researchers determined that a common pattern included activation in midline structures in the frontal and parietal lobes. This finding is largely consistent with the brain activity that has been shown to be related to self- and other-referential processing (D'Argembeau et al., 2008). It was also found that autobiographical memory, prospective memory, and theory of mind tasks activate Default Mode Network (DMN) regions, yet it is still unclear whether the DMN is actually responsible for these kinds of processing.

The brain activity associated with false memories using the misinformation paradigm has also been investigated. Okado and Stark (2005) used fMRI to examine participants' brain activity during the encoding of an event, and when receiving misinformative feedback in order to see whether the neural activity during either phase would predict what would be remembered. Specifically, the participants studied eight vignettes (this was the original event phase), and shortly afterward they studied the same vignettes but with changes to several details (the misinformation phase). It was found that neural activity recorded during encoding of the original event phase and misinformation phase predicted whether true or false information were later reported. . This study highlights that the processes at play when encoding information play a critical role in determining true and false memory outcomes in the misinformation paradigm, likely because one must re-evaluate their memory when provided with discordant information.

New Frontiers: Functional Near-Infrared Spectroscopy (fNIRS)

Neurophysiological and neuroimaging techniques have contributed greatly to our understanding of the structure and function of the human brain, as well as to the underpinnings of many different neurological and psychiatric disorders. Many of the researchers studying the neural coordinates of autobiographical memory retrieval use neuroimaging devices such as Functional Magnetic Resonance Imaging (fMRI) or Positron Emission Tomography (PET) to investigate brain regions responsible for memory and its related processes (Rubin, 2006). With increasing popularity in the area of cognitive neuroscience, another way to investigate this phenomenon is using Functional Near Infrared Spectroscopy (fNIRS).

What is Functional Near-Infrared Spectroscopy (fNIRS)?

Functional Near-Infrared Spectroscopy (fNIRS) is an emerging neuroimaging technique that is commonly used to measure brain activation in clinical settings, in emergency medicine, and in research. fNIRS is a non-invasive optical technique that uses near-infrared light to measure changes in the concentration of oxygenated (HbO) and deoxygenated (HbR) hemoglobin in the cortex, to identify the level of cerebral oxygenation *in vivo* (Rossi et al., 2012). The founder of in vivo NIRS is Frans Jöbsis-van der Vliet, who actually discovered its utility when he noticed that red light could penetrate through a 4-mm-thick bone of a beef steak when being held against visible light. He then moved to more relevant avenues when he demonstrated the application of NIRS in laboratory animals (Vliet, 1999) and for bedside monitoring of cerebral oxygenation in sick newborn infants (Brazy et al., 1985). The first fNIRS human study utilizing a single-site measurement was published in 1993 (Hoshi & Tamura, 1993). Since then, fNIRS has been used to study many different brain-related diseases, disorders, and functions. Research areas such as Alzheimer's disease, depression, memory, language, the brain-computer interface and pain have been studied using fNIRS over the last 30 years (Ferrari & Quaresima, 2012).

How does fNIRS Function?

The human brain undergoes a number of physiological changes as it responds to stimuli. By measuring the change in the oxygenation of hemoglobin molecules in the blood, fNIRS is able to quantify the level and location of neural activity in the brain. These changes in blood levels and electrochemical activity also affect its optical properties (Bunce et al., 2006). This is because the absorption spectrum of hemoglobin is

largely dependent on its level of oxygenation. There are two principles that NIRS relies upon: (1) that the tissue is transparent enough that near-infrared light can shine through (the NIR spectral window is 650-1000nm), and (2) that there are compounds within that tissue (chromophores) for which the absorption of light is dependent on the oxygenation of that tissue (Bakker et al., 2012). The moderately high attenuation of NIR light in tissue is due to hemoglobin, which is located in small blood vessels in the brain such as the capillary, arteriolar, and venular beds (Ferrari & Quaresima, 2012).

The Hemodynamic Response. Changes in cerebral blood flow and blood oxygenation occur upon neural activation in the brain. This *hemodynamic response* is described as an increase in the blood flow to the cortical tissue when there is an increased level of activity in certain brain regions (Bauernfeind et al., 2014). For brief sensory events, the hemodynamic response is delayed in onset and occurs about 2 seconds after neuronal activity (Blamire et al., 1992). This increase in neural activity causes a drop in glucose and oxygen stores, triggering a neurochemical cascade which results in the vasodilation of the blood vessels to the active brain area. This in turn, causes an influx of blood that is rich in oxygenated hemoglobin, reaching a state of equilibrium after approximately 30 seconds (Bauernfeind et al., 2014; Tak & Ye, 2014).

The canonical hemodynamic response function (HRF) is widely used in fNIRS and fMRI research and is an essential step in the statistical analysis of both modalities of data collection. The typical hemodynamic response in adults has been well-established and demonstrates an increase in oxygenated and total hemoglobin concentrations and a decrease in deoxygenated hemoglobin concentration with demonstrated reproducible and consistent results (Plichta et al., 2006, 2007). By using this a-priori knowledge of what

functional activity for the task should look like (i.e., peak of the canonical hemodynamic response), data collected via fNIRS can be compared to this model in order to determine the overall fit, which is represented by General Linear Model (GLM)-generated "peak" beta coefficients.

NIRS techniques. There are three different NIRS techniques that are used, each of which are based on a different type of illumination. The first is the continuous-wave (CW) modality, which is based on the constant illumination of the tissue to measure the light attenuation through the head. Second is the frequency-domain (FD) method, which illuminates the head with intensity-modulated light, measuring both attenuation and the phase delay of the emerging light. Lastly, the time-domain (TD) technique illuminates the head with short pulses of light and then detects the shape of the pulse after its propagation through the tissue (Ferrari & Quaresima, 2012). Ferrari and Quaresima (2012) add that only the FD and TD techniques fully characterize the optical properties of the tissues (absorption and reduced scattering coefficients), which makes it possible to retrieve absolute oxygenated and deoxygenated hemoglobin concentrations.

In the current study, the frequency-domain method is utilized by our ISS Imagent System (ISS Medical, 2016). The data to be collected includes information regarding the average magnitude (DC), amplitude (AC), and the phase of the signals, for each channel. Each data collection cycle contains an average waveform for each light source, resulting in 16 sets of data per cycle for a system with eight sources (each containing a paired fiber optic cable carrying 690 and 830nm light) and two detectors.

Advantages of Using fNIRS

The major advantages of optical techniques are the specificity, the temporal resolution (which is in the millisecond range), the potential to measure intracellular/intravascular events simultaneously, and the ease with which devices can be transported (Pinti et al., 2018). Because of this, and the fact that it is non-invasive and safe, fNIRS has become quite popular in many different settings. By utilizing laser diodes that span the optical window of 650-1000nm, and flexible fibre-optic cables to carry the NIR light from the source to the detector, fNIRS can be used in different head positions and postures (Ferrari & Quaresima, 2012). The placement of the apparatus can be done in natural environments without the need for restraint or sedation. Similar to fMRI, fNIRS systems rely on similar principles of cerebrovascular activity. However, fNIRS is much less expensive to buy and maintain, is safe for those for whom MRI would be unsafe (e.g., those with metallic implants, those with past surgery, and those with claustrophobia), and is more portable and thus creates more natural testing situations. This allows for standard psychological and neuropsychological testing to be conducted without the need for much adaptation (Ferrari, Ferrari, & Quaresima, 2007; Noah et al., 2015). Like fMRI, the changes in blood oxygenation that occur in response to certain tasks or stimuli can be measured, and these changes can be attributed to differing levels and locations of cortical activity (Fantini, 2014; Scarapicchia et al., 2017). fMRI relies on the Blood Oxygen-Level Dependent (BOLD) signal to measure only deoxygenated hemoglobin, whereas fNIRS measures both oxygenated (HbO) and deoxygenated (HbR) hemoglobin, thus allowing for a better understanding of the hemodynamic forces occurring in the brain (Bakker et al., 2012).

Disadvantages of Using fNIRS

It is clear that there are many advantages to using fNIRS as a neuroimaging device, however there are several disadvantages that should also be discussed. fNIRS has low spatial resolution, and its penetration depth is only about 1.5-2 centimeters. This means that it is impossible to gather information related to structure and anatomy of the brain (Pinti et al., 2018). As well, fNIRS is susceptible to motion errors (however, all imaging modalities encounter motion artifact limitations), nonetheless several techniques have been developed to correct for them (Scholkmann et al., 2010; Brigadoi et al., 2014). Potentially the most substantial limitation is the lack of standardization in the pre-processing and data analysis procedures used when conducting studies with fNIRS; to date there is neither an agreement nor guidelines on the analysis of fNIRS data as in other well-established technologies like fMRI (Pinti et al., 2018; Pinti et al., 2019).

fNIRS Data Analysis

Since fNIRS was developed, it has grown rapidly, with the number of publications doubling every 3.5 years (Boas et al., 2014). Recent advances in this technology have allowed researchers to examine neurovascular physiology with both increased resolution and quality. However, due to the rapid increase in new users employing various commercial software's using various different fNIRS machines, there is increasing concern that many studies may be biased by suboptimal processing methods (Pfiefer et al., 2018). Hocke et al. (2018) state that due to the lack of standardized and automated processing and analysis of fNIRS data, it is difficult to reproduce studies, which can ultimately result in the misinterpretation of data by both novice and

experienced fNIRS researchers. Because of this, the current position on both fNIRS pre-processing and statistical analyses is discussed.

Pre-processing of fNIRS data. In a recent review by Pinti et al. (2019), the issue of heterogeneity in the analytic approaches and pre-processing procedures within the realm of fNIRS research are brought to light. The authors outline a sequence of four steps that should be followed when designing an fNIRS study (see Figure 2). Step three of this model focuses specifically on the pre-processing phase of fNIRS data analysis, which is when raw intensity fNIRS data are visually inspected in order to assess the signals' quality (i.e., to determine the presence and magnitude of large motion artifacts, heartbeat oscillations), and then adjusted. fNIRS signals generally contain two types of noise: physiological noise and non-physiological noise. Physiological noise includes systemic interference that is driven by changes in blood pressure due to cardiac processes, respiration, Mayer waves, and low-frequency oscillations (Elwell et al., 1999; Saager & Berger, 2008; Gregg et al., 2010) or indirectly by head/body movements (von Luhmann et al., 2020). On the other hand, non-physiological noise involves motion artifacts that are caused by optode-scalp decoupling (Cooper et al., 2012; Brigadoi et al., 2014) and other instrumental noise. In order to ensure that the fNIRS data is correct and therefore useful, any source of variability in the oxygenated (HbO) and deoxygenated (HbR) hemoglobin that is not related to the hemodynamic activity evoked by a task should be removed or minimized.

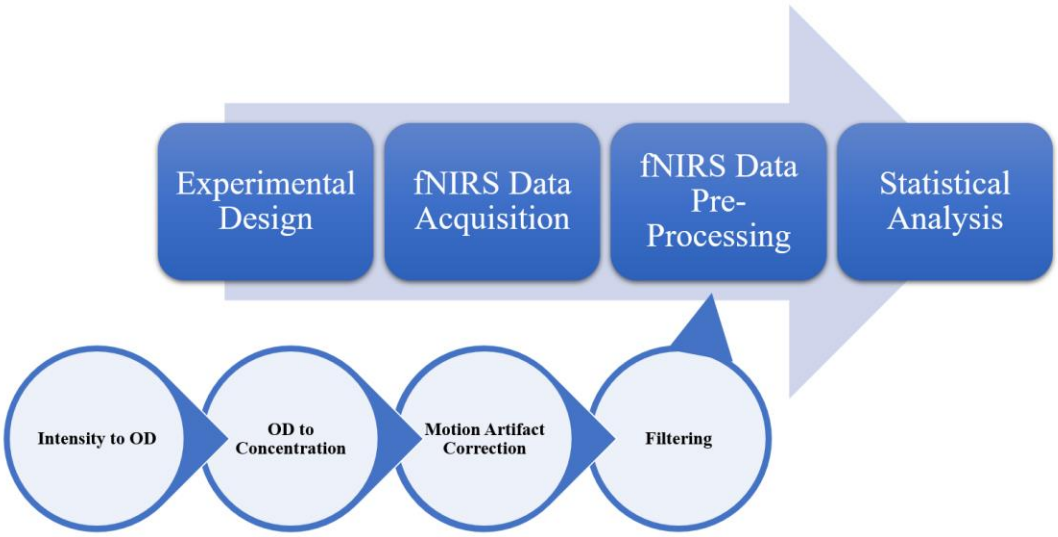

Figure 2. A typical fNIRS experimental pipeline as outlined by Pinti et al. (2019).

Pinti et al. (2019) discuss that digital filtering (a mathematical procedure) is applied in order to reduce or enhance certain aspects of input signals. These digital filters are divided into three classes: (1) *high-pass filters*, which are used to remove high frequency components above the cut-off frequency; (2) *low-pass filters*, which are used to remove low frequency components that are below the cut-off frequency; and (3) *band-pass filters* which are used to preserve the frequency range between a lower and a higher cut-off frequency. Pinti et al. (2019) stress that the pre-processing pipeline followed by researchers is exceedingly important, since this data manipulation can impact subsequent group-level statistical analyses. In other words, a mistake made during data pre-processing can render your study's findings as useless.

Huppert (2016) provides a review of the noise structures that can often be seen in fNIRS data, highlighting the impact that noise can have on some statistical tests. When the assumptions of statistical tests are violated by properties of fNIRS such as serially correlated noise due to physiology or outliers in the normal noise distribution due to

motion artifacts, Huppert (2016) suggests two possible ways of remediating the problem. First, we can remove the noise/artifacts from the data. However, a common problem with this is that there is no perfect method of removing all types of artifacts. This in turn, makes it subjective and thus relies upon the researcher's expertise to select and use the signal processing tools correctly. If noise is incompletely removed, assumptions of the statistical model can still be violated, leading to inaccurate reporting of the results. A second suggested approach to handling noise artifacts is to leave the data alone and instead change the assumptions of the statistical model, allowing for a more generalized model that can handle the properties of the artifact without violating assumptions.

Von Luhmann and colleagues (2020a; 2020b) agree that in order to recover underlying brain activation patterns during pre-processing, researchers need to carefully remove or modify these confounding factors from the fNIRS signal. Therefore, these pre-processing corrections can either be applied prior to the hemodynamic response function (HRF) estimation or, ideally, simultaneously with the HRF estimation as is the case with the General Linear Model (Friston, 1994; Cohen-Adad et al., 2007). The General Linear Model (GLM) is especially useful because it allows for the simultaneous extraction of the evoked HRF while filtering confounding signals with the help of nuisance regressors (short-separation fNIRS measurements) (Zhang et al., 2007; Saager & Berger, 2008; Gagnon et al., 2011). Von Luhmann et al. (2020b) explain that this allows the contrast to noise ratio (CNR) of the evoked hemodynamic brain activity to be increased, and the risk of falsely classifying task-evoked systemic physiology instead of brain activity is reduced. This therefore enhances accuracy, sensitivity, and specificity of fNIRS single trial classification.

Statistical analysis of fNIRS data. In a recent review by Yücel et al. (2017), the authors describe that after the pre-processing phase and cleaning of the data are complete, a statistical model is to be used to detect the differences in the level of hemoglobin between pairs of tasks or between a task and baseline. As mentioned by von Luhmann et al. (2020b), the current state-of-the-art analysis in fNIRS research is the General Linear Model with Short-Separation regression (GLM with SS), which can be implemented either during or after pre-processing. This method is important because it uses measured hemoglobin changes modeled as linear combinations of regressors derived from the timing of the stimulus events (Yücel et al., 2017). As highlighted by Tak and Ye (2014), Huppert (2016) and Pinti et al. (2019), there is continued debate about the optimal model to use with fNIRS data analysis in order to maximize sensitivity, and when to apply this model is also in question (von Luhmann et al., 2020). As statistical methods continue to be proposed and utilized, Yücel et al. (2017) describe that there is an increasing need for more rigorous comparisons of the tradeoffs in the sensitivity and specificity of these methods.

Past studies such as Murata et al. (2002) simply calculated the concentration changes of hemoglobin oxygenation during their task period and then depicted the time-series of cerebral oxygenation changes for visual inspection. Tak and Ye (2014) discuss that such simple approaches as this are prone to error, particularly when the noise and interference level increases. They discuss that various different statistical analysis methods have been used in the past to compare means, including t-tests (Germon et al., 1994; Hoshi et al., 2003), and multi-way ANOVAs (Arenth et al., 2007; Bartocci et al. 2000). The problem with these methods, however, is that the time course in fNIRS is

directly related to the hemodynamic response, and when using these simple statistics, information about the time course is lost.

In order to overcome some of these weaknesses, the General Linear Model (GLM) began to be used, which assumes that data can be represented as a linear combination of several sources or regressors (Friston et al., 2011). The first to apply the GLM to analyze fNIRS data was Schroeter et al. (2004), and since then numerous authors have employed this method of statistical analysis (Tak & Ye, 2014). A GLM is a flexible generalization of an ordinary linear regression model which allows for the response variables to have errors distributions other than the normal distribution. As mentioned, this is what most researchers have agreed upon as best practice for fNIRS statistical analyses today (Yücel et al., 2017). In a recent study by Jahani et al. (2017), the authors estimated a hemodynamic response function (HRF) by using a GLM, which was then used to attain information about the time course of the data in the form of beta coefficients. Paired student's t-tests were then conducted on these beta coefficients to evaluate the statistically significant differences in hemodynamic responses to their stimuli. Of course, due to multiple comparisons often leading to an inflated type I error rate, a Benjamini-Hochberg multiple comparison correction is recommended to be applied (Jahani et al., 2017; Yu et al., 2020). This is the approach that was followed in the current study, as it is deemed to be the leading method of statistical analysis of fNIRS data.

The Current Study

This research project was designed to explore the neural activity of healthy adults' metamemorial appraisals of belief in occurrence and belief in accuracy using Functional

Near-Infrared Spectroscopy (fNIRS). The results of this study will provide the first investigation of the neurological plausibility of Scoboria's (2020) model, thus allowing for the cortical dissociation between the metamemorial appraisals of belief in accuracy and belief in occurrence to be made. Therefore, this study aims to demonstrate differential activation patterns based on cognitive consistency and dissonance. The preceding literature review demonstrates the importance of understanding these appraisals, highlighting the impact that feedback from others can have on remembering. In order to understand the broad effects of disconfirmatory social feedback, we must first appreciate the distinct underlying cognitive mechanisms at play.

When memories are challenged by others, this can lead to changes in one's belief in the occurrence and/or the accuracy of their memory. Past research (Scoboria, Talarico, & Pascal, 2015; Korcsog 2017; Korcsog 2018; Korcsog et al., In Preparation) has demonstrated that experimentally providing disconfirmatory feedback about scene occurrence and the content of a scene results in a distinction between belief in accuracy and belief in occurrence appraisals. Korcsog (2017; 2018) and Korcsog et al. (In Preparation) were the first to use procedures that implemented stimuli with a narrative structure, reflecting the narrative coherence that Rubin (2006) describes autobiographical memories to have. The next step in this line of research is to investigate whether the regions of the brain that are active when receiving and evaluating feedback about occurrence and accuracy are distinct in their location and/or their level of activation in the brain.

The first research question is whether the level and location of oxygenated hemoglobin in the left prefrontal cortex will differ when participants receive feedback

about the occurrence vs. the accuracy of their memory. Conway et al., (1999) found that the left frontal cortex was active during the retrieval of autobiographical memories, and so a left frontal cortical array was created in order to measure activation when participants receive feedback about their memory. It was hypothesized that there will in fact be a difference in activation, since it has been demonstrated that despite being rated highly synonymously, these appraisals can be dissociated (Scoboria, Talarico, & Pascal, 2015; Korcsog, 2017; Korcsog, 2018; Otgaar et al., 2018; Korcsog et al., In Preparation). Because of this proposed dissociation, the neurocognitive mechanisms that are used to differentiate knowledge of memory occurrence and accuracy may be distinct. As well, research on the mental construction of details versus the mental construction of whole scenes demonstrates that different brain regions contribute to each. In one study by Summerfield, Hassabis, & MacGuire (2010), the mental construction of details activated areas such as the hippocampus and the retrosplenial cortex, whereas the mental construction of whole scenes activated the left and right ventrolateral prefrontal cortex.

The second research question is whether there will be a distinction between the level and location of brain activity associated with confirmatory vs. disconfirmatory feedback about memory accuracy and occurrence. In other words, will the brain activity associated with telling a person that they are correct about the occurrence of a memory differ from when the same person is told that they are incorrect about the occurrence of that memory (i.e., telling the participant that the event that they remembered did not actually occur in the past). As well, will the left frontal activity associated with telling a person that their description of a memory was accurate differ from telling a person that their description of a memory (that *was* accurately recollected) was inaccurate? When

participants receive disconfirmatory feedback, it was expected that they would experience cognitive dissonance. One study by Van Veen and colleagues (2009) describes that when people experience cognitive dissonance, the dorsal anterior cingulate cortex and anterior insula are engaged. Because fNIRS is unable to measure the activity of these deep brain structures, it is impossible to determine whether dissonance has occurred. However, it has been demonstrated that the dorsolateral prefrontal cortex is involved in decision making (Rosenbloom, Schmahmann, & Price, 2012) and in reasoning (Goel & Dolan, 2004). Because of this, it is hypothesized that when given disconfirmatory feedback about a memory, decision-making processes will come into play in order to determine whether to accept or reject the feedback. This in turn, should result in increased activation of the dorsolateral prefrontal cortex.

In further exploration of the second research question, participants' responses to disconfirmatory feedback about memory accuracy and occurrence will be compared to their belief in accuracy and belief in occurrence rating items. This will be done in order to determine whether ratings reflecting relinquishment of memory show different patterns of brain activation than ratings reflecting maintenance of memory. It was hypothesized that regardless of whether participants chose to hold on to or relinquish their memory, reasoning and decision-making processes would come into play, thus resulting in increased activity in the left dorsolateral prefrontal cortex.

CHAPTER 2

Method

Participants

Twenty-four participants were recruited through the University of Windsor Participant Pool, and all participants apart from those who had a visual or auditory impairment or those who had participated in a study with a similar deceptive component in the past (i.e., The Actions Study 2014-2017 or Remembering Recorded Events 2017-2019) were eligible to participate. Of these 24 participants, 17 possessed adequate fNIRS signal strength to be included in the statistical analyses (88% female, 68% Caucasian; M_{age} = 21.94, SD = 4.18, range 19-31). All participants received academic credit for completing the study, regardless of whether or not adequate fNIRS signal strength was obtained.

Measures

Belief in Occurrence

Two items derived from Scoboria et al. (2004) were included to assess belief in occurrence before and after the participant was challenged about their memory for the occurrence of scenes. The items were measured using 7-point Likert-style scales and were averaged to calculate the scale score. See Appendix A containing the verbatim presentation of these questions.

Belief in Accuracy

Two items derived from Scoboria, Talarico, and Pascal (2015) were included to assess belief in accuracy before and after the participant was given feedback about their memory for the details within scenes. The items were measured using 7-point Likert-style

scales and are averaged to calculate the scale score. See Appendix A for the verbatim presentation of these questions.

Event Recordings

Sixty scenes were presented to each participant, 30 as silent videos and 30 as audio recordings. There was a 5-second delay between each scene, where a black screen with a white target was shown in order to re-direct attention to the computer screen. A JVC Everio GZ-HM200 Dual SD High Definition Camcorder was used to record all of the videos that were used as stimuli in this study and were recorded in October 2016 as a part of Korcsog's (2017; 2018) study. An ASUS Zenbook UX303UA-DH51T Intel i5 computer was also utilized in October 2016 to record all the sound recordings that were presented in this study. Each of the recorded scenes were under 35 seconds in length and contained at least four steps, with all of the scenes being neutral in nature and relatively simple (see Appendix B for a list of the titles of the scenes that were presented to participants, and Appendix C for a list of the titles of the scenes that were prompted but never presented). Each scene depicted the same actress, a 15-year old girl, who gave permission for the recordings to be used. The scenes were kept relatively similar, meaning that they all consisted of the same actress, wearing the same clothes, doing everyday tasks. All items used in the scenes were common household objects. A sample of what three of the scenes looked like is found in Figure 3, and a sample transcription of what one of the auditory scenes sounded like is provided in Appendix F.

Figure 3. Three examples of simple scenes that were presented to participants, also presented in Korcsog (2018). From top to bottom the scenes are: A girl washing dishes, a girl hitting a baseball, and a girl making a sandwich. Each video-recorded scene was under 35 seconds in length and consisted of at least 3 steps. The videos were muted so participants would receive only visual stimulation.

fNIRS Probe Placement

The NIRS probe was designed using AtlasViewerGUI software (Aasted et al., 2015). The probe design and the probe itself can be seen in Figure 4. The probe consists of eight sources and two detectors, with short-separation channels being 10mm apart and long-separation channels being 30mm apart. There are 16 channels containing two different wavelengths, totaling a total of 32 channels. This probe covers the left prefrontal cortex (Figure 4; Brodmann's areas 8, 9, 10, 44, & 45).

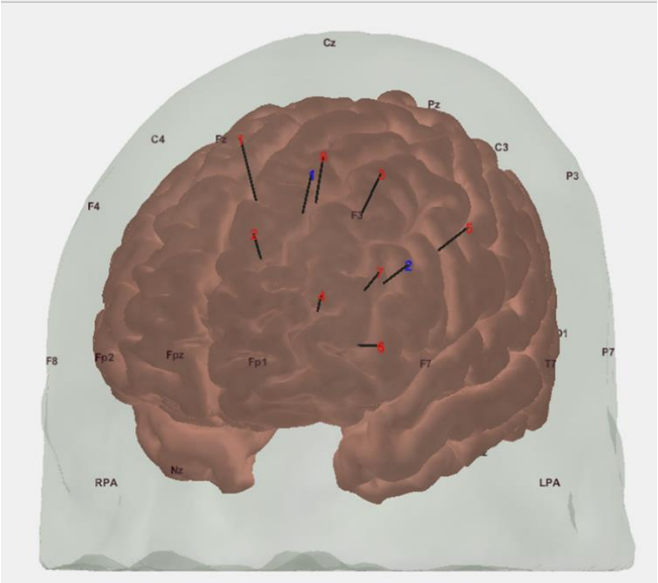

Figure 4. Pictorial depiction of the configuration of the fNIRS array as displayed by AtlasViewerGUI. The red numbers denote the optode locations and the blue numbers denote the detector locations. The anatomical landmarks derived from the 10-20 system are labelled in black.

fNIRS System

Data were acquired using the ISS Imagent System (ISS Medical, 2016) which utilizes laser diodes at 690 and 830nm and acquires signals from the photo-detectors at a modulation frequency of 110Hz. ISS Imagent (ISS Medical, 2016) is a frequency-domain (FD) system consisting of 16 optical channels, each with two wavelengths. The 10mW average powered laser light is carried from the FD system to the head probe via optical fibers and is delivered from the head probe back to the FD system through detector fiber bundles.

Procedure

Session 1

After completing the consent process, participants were asked to sit in front of a computer and to put on the provided headphones. They were instructed to watch and listen carefully to 30 silent videos and 30 audio-recorded descriptions (with no visual stimuli) of an actress performing simple tasks (see Appendix B for a list of the titles of these tasks that were presented during session 1). Each of these scenes were under 35 seconds in length, and the mode of presentation (video vs. audio) was counterbalanced among participants. The recordings alternated randomly between video and audio-recorded scenes, with a 5-second delay in between each scene. See Figure 3 for a visual depiction of these scenes and Appendix F for a transcription of an audio-recorded scene.

Session 2

Session 2 took place exactly one week after session 1 and was divided into two parts: Phase 1 and Phase 2. During Phase 1, termed "The Recognition Phase", participants were asked questions about their memory for 90 scenes. 30 questions were about scenes that were presented as a video, 30 questions were about scenes that were presented as an audio-recording, and 30 questions were about scenes that were never actually presented (see Appendix C for a list of the titles of scenes that were prompted, but never actually presented to participants). First, participants were asked whether each scene was presented in session 1. If they answered "yes", they were then asked if the scene was presented as a video or as an audio recording. Then, they were asked to describe the scene. Finally, the participant was asked to rate their belief in the occurrence

and belief in the accuracy of their memory using the aforementioned scales found in Appendix A.

During Phase 2, "The Feedback Phase", the Functional Near-Infrared Spectroscopy (fNIRS) was set-up and feedback was administered whilst recording each participant's brain activity. At least two researchers were present for this portion of the study, one of them provided the feedback to the participant while the other ran the fNIRS machine and created time-stamps when each form of feedback was given. The researcher who was running the fNIRS data collection was laser safety trained and had been thoroughly trained on fNIRS safety protocol. Anatomical landmarks of the skull were measured using the 10-20 system (commonly used in EEG research), and temporary markings were made using medical tape to indicate the positions that the left prefrontal array were to be oriented in. Once the landmarks were set, the neoprene cap was secured using a combination of Velcro and fabric straps (in order to ensure a snug and comfortable fit). This cap held the optode mounts, and for each participant, each mount was examined in order to ensure that a clear view of the scalp was available, and hair was parted or moved slightly using a soft plastic rod or Q-tip. After this, the optodes and detectors, which were secured in a plastic enclosure, were secured to the cap's mount. Only at this time was the laser bank turned on in order to prevent accidental exposure to the laser light during the mounting process.

Once the lasers were turned on, the data collection software was initiated, and an automated signal optimization process was carried out. If any of the optodes needed to be adjusted due to poor signal strength (i.e., due to having an obstructed view of the scalp due to hair), the laser bank was turned off before the optode in question was removed,

cleared, and reseated. After adequate signal strength was confirmed, the software was set to record. The data captured includes: a timestamp of the data point (system time, in seconds), the marker that was set (to signal the feedback being given to the participant, the end of the feedback, and after a 10 second delay, the beginning of the questioning), and three forms of signals for each of the source-detector pairs (16 pairs in the current set-up): amplitude, the moving average value, and the phase/variance of the signal. No identifying information was recorded through this software, and participant data was deidentified by use of a participant number and condition (e.g., 07.B2).

There were 10 instances of feedback about randomly selected scenes that participants had accurately remembered as being presented as a video in session 1. Each instance of feedback had an epoch length of approximately 35-40 seconds in order for the hemodynamic response to reset. For 2 scenes, participants were given *positive* feedback about event occurrence (i.e., "you were correct in saying that a scene of a girl ___ was presented"), for 2 scenes participants were given *negative* feedback about event occurrence (i.e., "you were incorrect in saying that a scene of a girl __ was presented"), for 2 scenes participants were given *positive* feedback about memory accuracy (i.e., "in the scene of a girl __ you remembered more than 90% of the details correctly") and for 2 scenes participants were given *negative* feedback about memory accuracy (i.e., "in the scene of a girl __ you remembered less than 50% of the details correctly"). Finally, there were 2 scenes for which participants did not receive any feedback about their memory (i.e., "please re-rate the scene __"), which acted as a control condition. For a summary of the feedback conditions, see Table 1. Participants were asked to re-rate all 10 of these

scenes with the same belief in accuracy and belief in occurrence items as used before receiving social feedback (see Appendix A).

Table 1.

A summary table depicting all five forms of social feedback presented to participants.

	Belief in Accuracy	Belief in Occurrence
+	" In your description of the scene _____, you remembered more than 90% of the details correctly."	" You were correct in saying that a scene of a girl _____ was presented."
-	"In your description of the scene _____, you remembered less than 50% of the details correctly."	"You were incorrect in saying that a scene of a girl _____ was presented."
0	"Please re-rate the scene _____."	

Note. The "+" denotes positive/confirmatory feedback, the "-" denotes negative/disconfirmatory feedback, and the "0" denotes no feedback/control.

After the completion of the study, participants were asked the following questions: "What do you think that we are studying today?" and "how did you feel when you were told that you recalled some of the scenes incorrectly?". Participants were then read a debriefing statement explaining why the use of deception in the study is necessary, and that the feedback given in this study is not indicative of their true memory abilities. They were informed as to which items they received deceptive feedback about. Then, the utility of the fNIRS was explained to each participant before asking whether they agreed for us to keep their data. Finally, each participant was asked what it was like for them to participate in our study and whether they had any questions before being prompted to leave (see Appendix D for the debriefing script).

The recorded fNIRS data was saved into a text file (.txt) with the time and date of the recording, as well as the participant's code. The laser bank was turned off, and the optodes and cap were removed from each participant. The surfaces of the optodes and their holders were disinfected with wipes, and the participant was provided with paper towel and a mirror to remove any perspiration that may have accumulated on their scalp and to re-style their hair. The participants' data was later converted to a MATLAB compatible .NIRS file for pre-processing.

Data Analysis and Statistics

fNIRS Data Pre-Processing

Both during and after the completion of each of the 24 participants, the data was visually inspected using the BOXY software provided by ISS Imagent (ISS Medical, 2016) in order to determine whether signal strength and quality was adequate. Of the 24 recruited participants, 17 participants were deemed to have adequate signal strength and quality, and thus were included in the analyses. The guidelines for establishing adequate signal quality by Orihuela-Espina et al. (2010) were used, which included obtaining an average amplitude (AC signal) of greater than 100, magnitude (DC signal) of 2000, and a signal variance (phase) of less than 10. Pre-processing of the data was completed using Homer2 Toolbox (Huppert et al., 2009), MATLAB, and NIRS-SPM MATLAB scripts (Ye, Tak, Jan, Jung, & Jang, 2009). Using a Boxy2Homer MATLAB script, the data were converted from a raw text file exported from BOXY into a NIRS format that Homer2 was able to process (Huppert et al., 2009). Light intensity data were converted to hemodynamic data using the optical density and modified Beer-Lambert Law commands (Yücel et al., 2016) available in the Homer2 processing stream (Huppert et al., 2009).

Because the hemodynamic signal moves along a temporal continuum over time, and thus starts to drift, a first order polynomial drift correction was implemented. This is a conventional method to eliminate system drift from the fNIRS device (Orihuela-Espina et al., 2010). In order to partially remove the effects of cardiac and respiratory noise on the signal and to reduce motion artifacts, a low-pass filter (0.5Hz) and a high-pass filter (0.02Hz) were applied to the data.

Slow-wave oscillations (e.g., Mayer Waves) can overlap with the hemodynamic response, thus making it difficult to remove without removing the signal from cortical activity (Tak & Ye, 2014). However, leaving Mayer waves in the signal can also inadvertently inflate type-I error (Pinti et al., 2019). Therefore, to allow for the removal of noise that is attributable to surface-level effects, short signal optodes that capture surface-level vascular changes were used as covariates for the deeper optodes using the short-signal GLM algorithm (Gagnon et al., 2011). Short-signal separation has become a widely used method to remove physiological noise from the cortical signal and is an effective means of reducing signal contamination without compromising the true cortical signal (Tak & Ye, 2014). After this was implemented, the resulting processing stream was considered to be a relatively pure concentration function for oxygenated, deoxygenated, and total hemoglobin for each channel, which consists of only cortical signal changes.

The processed signals were further separated by time into epochs based on experimental events. For the purposes of this study, the pre-event phase was during the feedback that was read to the participant, and the post-event phase was the 20 seconds after the feedback was given. The average activation pattern across each channel for each

epoch was produced using run-based processing which averages each participant's signal across multiple trials. These analyses were conducted across groups (type of feedback), averaging these runs across participants.

The separation of the signals between the channels was optimized using a short-signal GLM algorithm (Gagnon et al., 2014). This algorithm contains a GLM with a modified gamma function, which is able to effectively separate the hemodynamic response from each epoch's baseline. This allows for a clear and interpretable graph of the hemodynamic response to be created. The hemodynamic response function (HRF) was then estimated by using a general linear model (GLM) which uses the least squares method for estimating the beta coefficients of the consecutive basis functions. The GLM is especially important because it is used to incorporate the time course of the whole HRF for each subject, by generating beta coefficients by use of a linear regression analysis.

Statistical Analyses

For the statistical analyses of the pre-processed fNIRS data (which at this point, are in the form of GLM-generated beta coefficients), paired Student's t-tests were used to evaluate statistically significant differences in hemodynamic responses to each feedback condition in the time range of 5-10 seconds. This time range was used because this is when the hemodynamic response signal reaches its peak. Because of the large number of comparisons made using the paired Student's t-tests, a multiple comparison correction was applied using the Benjamini-Hochberg False Discovery Rate (FDR) method with a false discovery rate of 0.05. For the analyses of the change in belief in occurrence and belief in accuracy ratings (pre- vs. post-feedback) based on feedback condition, mean

change scores [post-pre] and 95% confidence intervals were calculated as per the Cumming (2014) method.

For qualitative analyses of fNIRS data, such as the description of activation profiles, the activation profiles provided for each epoch/condition within the Homer2 Toolbox (Huppert et al., 2009) and AtlasViewerGUI (Aasted et al., 2015) were used. The group averages were imported into the AtlasViewerGUI program which was used to better demonstrate the functional patterns on a brain model across the different feedback conditions and across participant relinquishment type. This created a map of functional activity on a standard brain atlas representing 3D space which allowed for easier visual comparisons to be made across feedback conditions and across relinquishment types.

CHAPTER 3

Results

The influence of social feedback on memory was examined by the use of Functional Near-Infrared Spectroscopy (fNIRS) in order to determine whether the neurocognitive mechanisms at play were distinct dependent on the type of social feedback received, and on one's response to this feedback. These analyses included the examination of the contrasts between each fNIRS channel, hemoglobin type (HbO, HbR, HbT), and condition (see Table 1), as well as between pre- and post-scores on the belief in accuracy and belief in occurrence rating scales (Appendix A).

fNIRS Analyses

The group mean (n=17 participants) temporal traces of the oxy-hemoglobin (HbO), deoxy-hemoglobin (HbR), and total hemoglobin (HbT) concentration changes from baseline levels after receiving different instances of social feedback are depicted in

Table 2. These p-values represent the significance levels of paired Student's t-tests performed on the average beta coefficients obtained from 5-10 seconds of the hemodynamic response function (HRF), representing the "peak hemodynamic response". A Benjamini-Hochberg False Discovery Rate (FDR) correction was applied to account for multiple comparisons. The group mean spatial results averaged over 5-10 seconds are also overlaid on brain surfaces for better visual presentation of the different brain regions involved in the different conditions of social feedback (see Figures 5-9). Channel 3,2 and 6,2 were removed from the analyses due to poor overall signal quality across participants. One participant was removed from the analyses for channel 5,2 due to poor signal strength resulting in loss of data.

Table 2.

Temporal traces of oxy-hemoglobin (HbO), deoxy-hemoglobin (HbR), and total hemoglobin (HbT) concentration changes by feedback condition.

Channel	# of Participants Included	MNI	Brodmann Area	Cortical Region	Ctrl vs. + Occ HbO HbR HbT	Ctrl vs. + Acc HbO HbR HbT	Ctrl vs. - Occ HbO HbR HbT	Ctrl vs. - Acc HbO HbR HbT	+ Occ vs. + Acc HbO HbR HbT	+ Occ vs. - Acc HbO HbR HbT	+ Occ vs. - Acc HbO HbR HbT	+ Acc vs. - Acc HbO HbR HbT	+ Acc vs. - Occ HbO HbR HbT	- Occ vs. - Acc HbO HbR HbT
1,1	17	-13 45 47	8	Medial Prefrontal Cortex	**.000** **.000** .176	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** .757 **.000**	**.000** **.000** **.000**	.119 **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**
2,1	17	-15 55 35	9	Dorsolateral/anterior prefrontal cortex	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.023** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**
3,1	17	-29 40 44	9	Dorsolateral/anterior prefrontal cortex	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.011** **.000** **.000**	.623 **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.015**	**.000** **.000** **.000**	**.000** **.000** **.000**
4,1	17	-30 54 29	10	Anterior Prefrontal Cortex	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** .071 **.000**	**.000** **.000** **.000**	.081 **.000** **.000**
4,2	17	-37 41 12	10	Anterior Prefrontal Cortex	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**
5,2	16	-48 28 28	45	Left inferior frontal gyrus opercularis	**.000** **.000** **.000**	**.012** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**	**.000** **.000** **.000**

Abbreviations. MNI = Montreal Neurological Institute and Hospital; Ctrl = Control; + Occ = Positive Occurrence; + Acc = Positive Accuracy; - Occ = Negative Occurrence; - Acc = Negative Accuracy; HbO = Oxygenated Hemoglobin; HbR = Deoxygenated Hemoglobin; HbT = Total Hemoglobin. *Note.* Students' paired samples t-tests were conducted on beta coefficients resultant from the linear regression of hemoglobin concentrations to the HRF. The depicted p-values were obtained from paired samples t-tests conducted on "peak beta coefficients" obtained from the 5-10 second range.

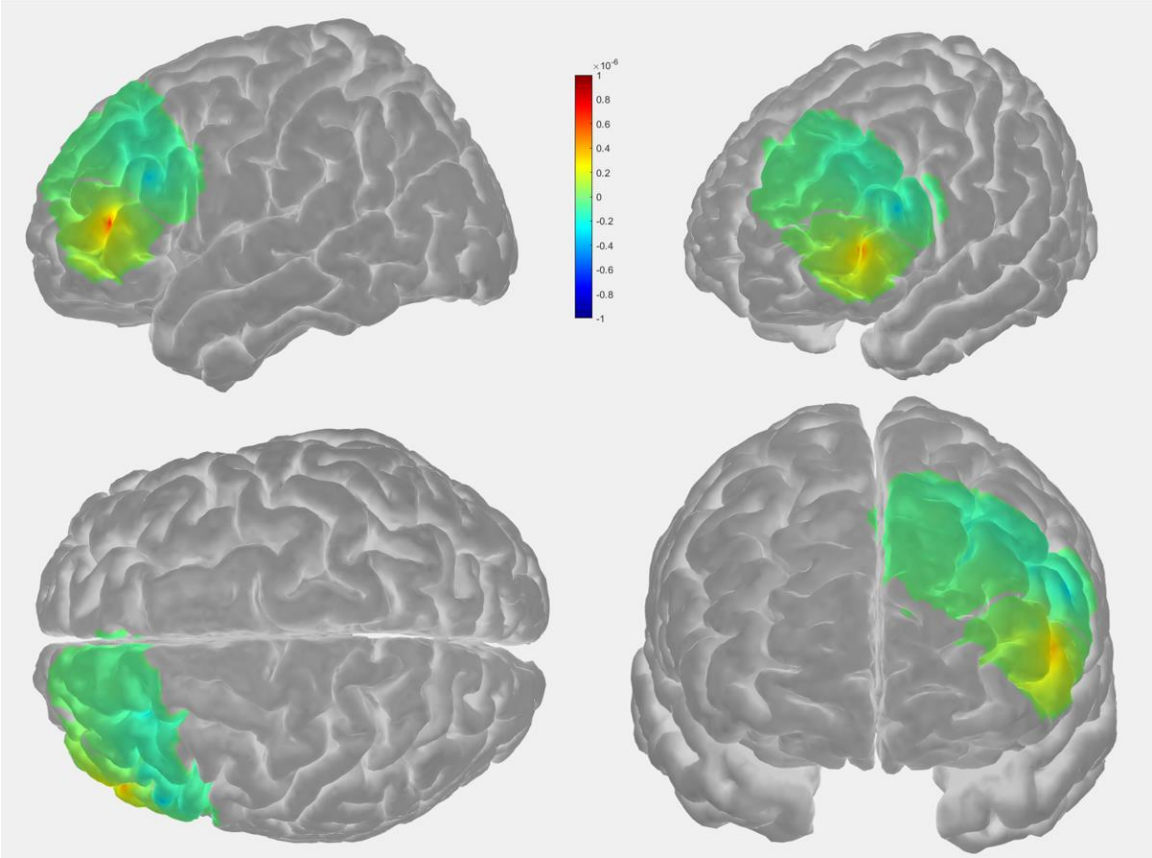

Figure 5. The average activation pattern of the control condition overlaid on a 3D image of the brain.

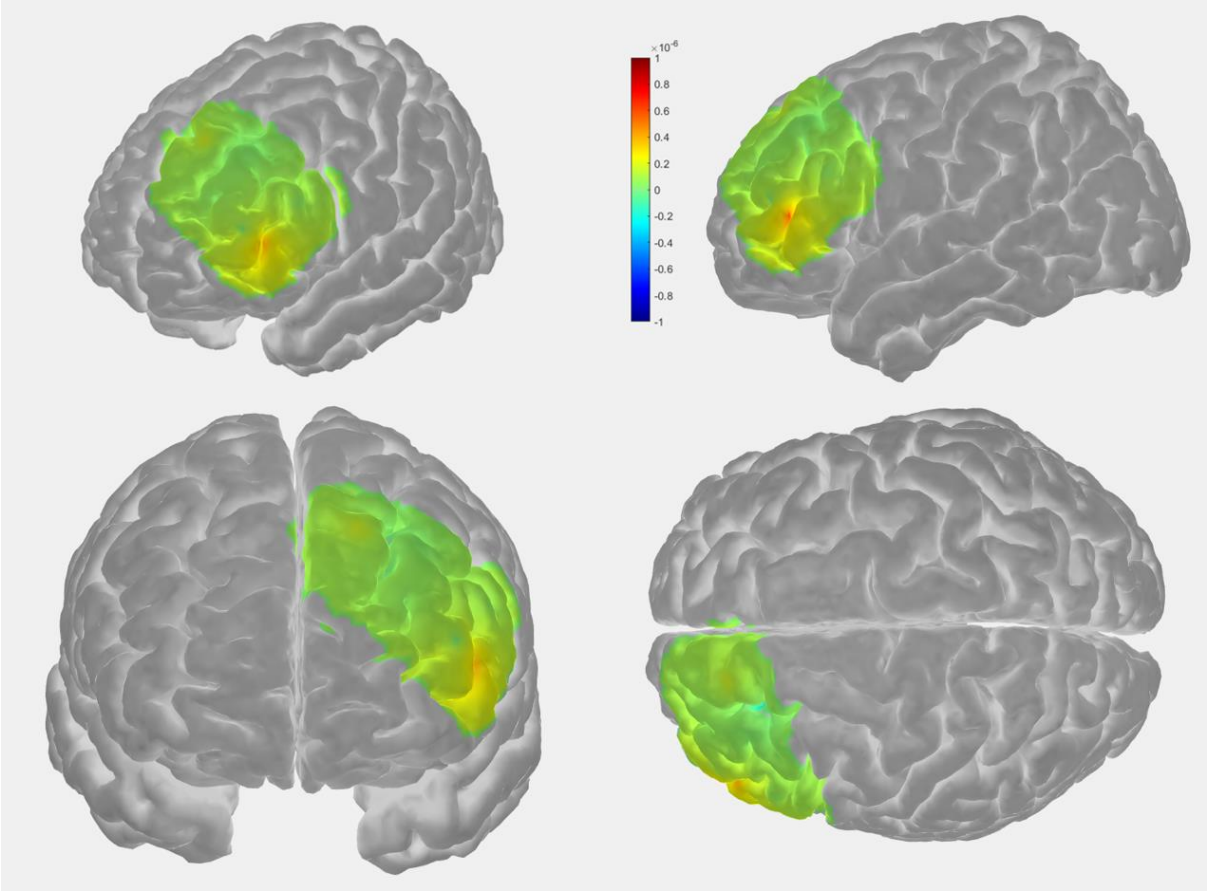

Figure 6. The average activation pattern of the "Positive Occurrence" condition overlaid on a 3D image of the brain.

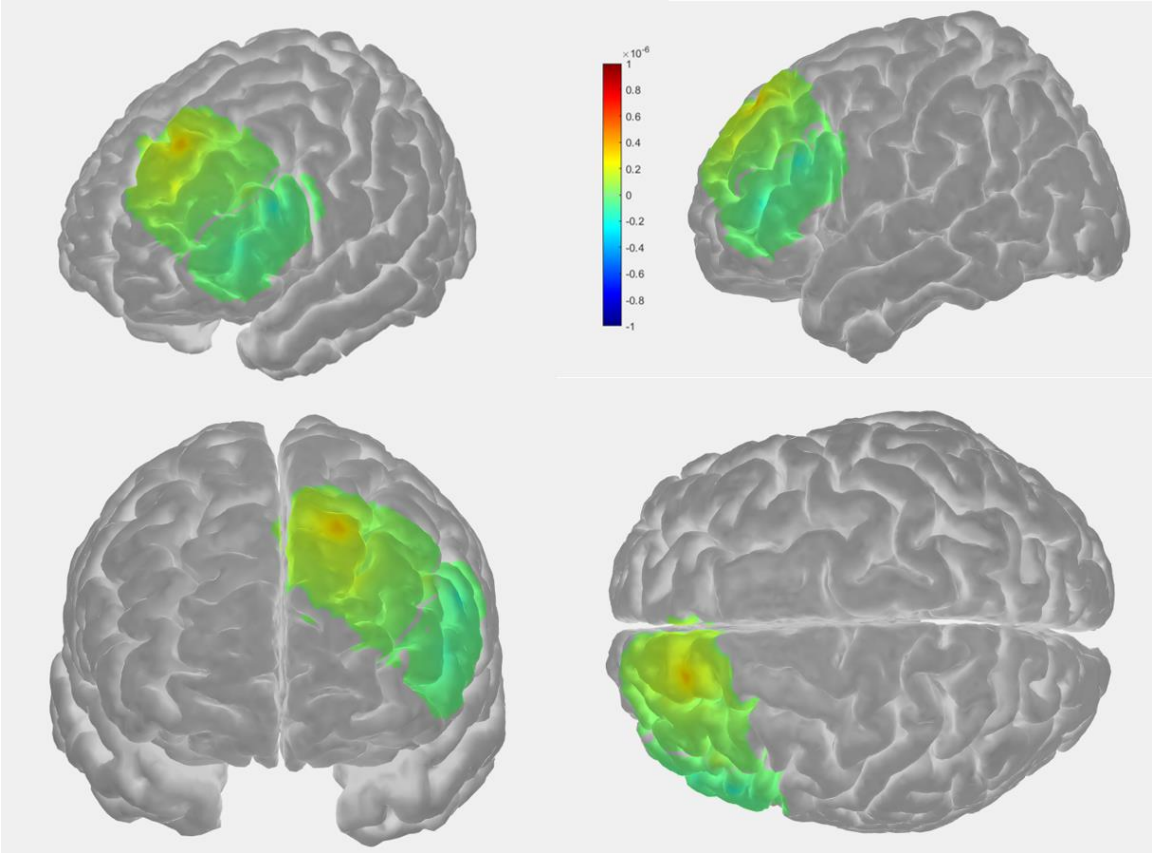

Figure 7. The average activation pattern of the "Positive Accuracy" condition overlaid on a 3D image of the brain.

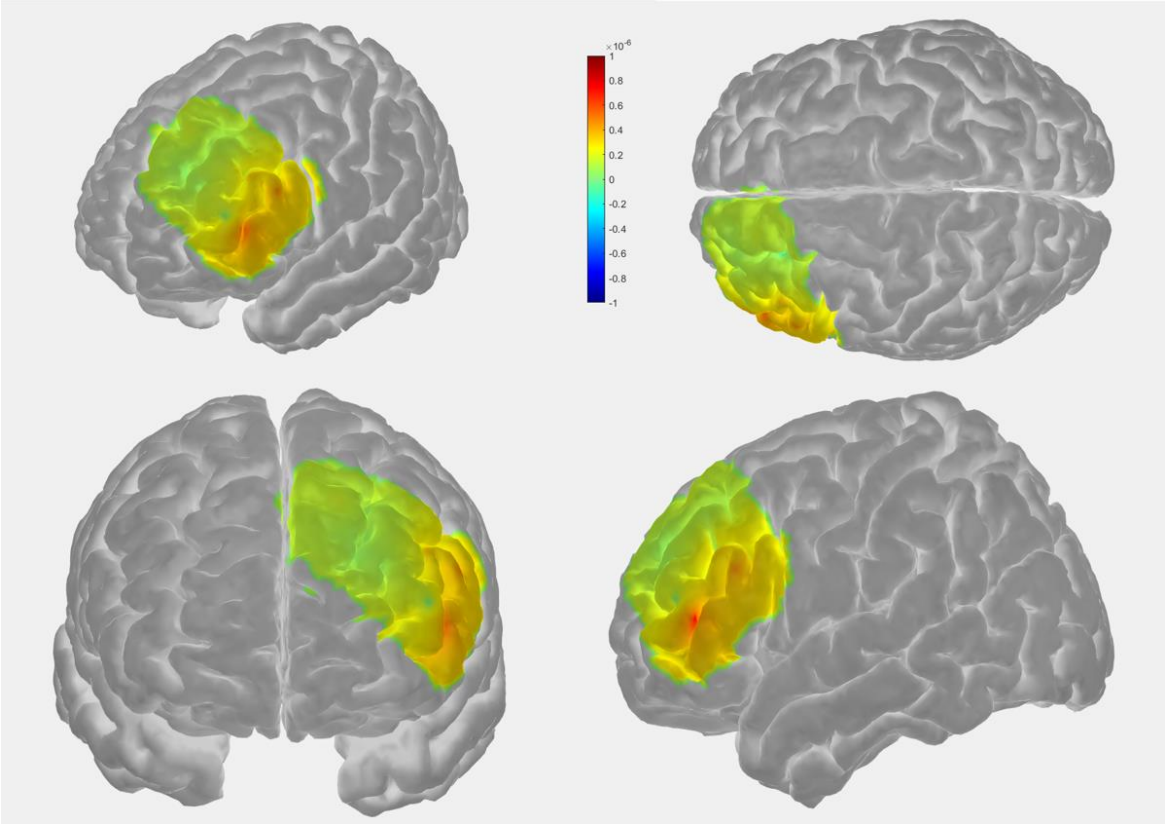

Figure 8. The average activation pattern of the "Negative Occurrence" condition overlaid on a 3D image of the brain.

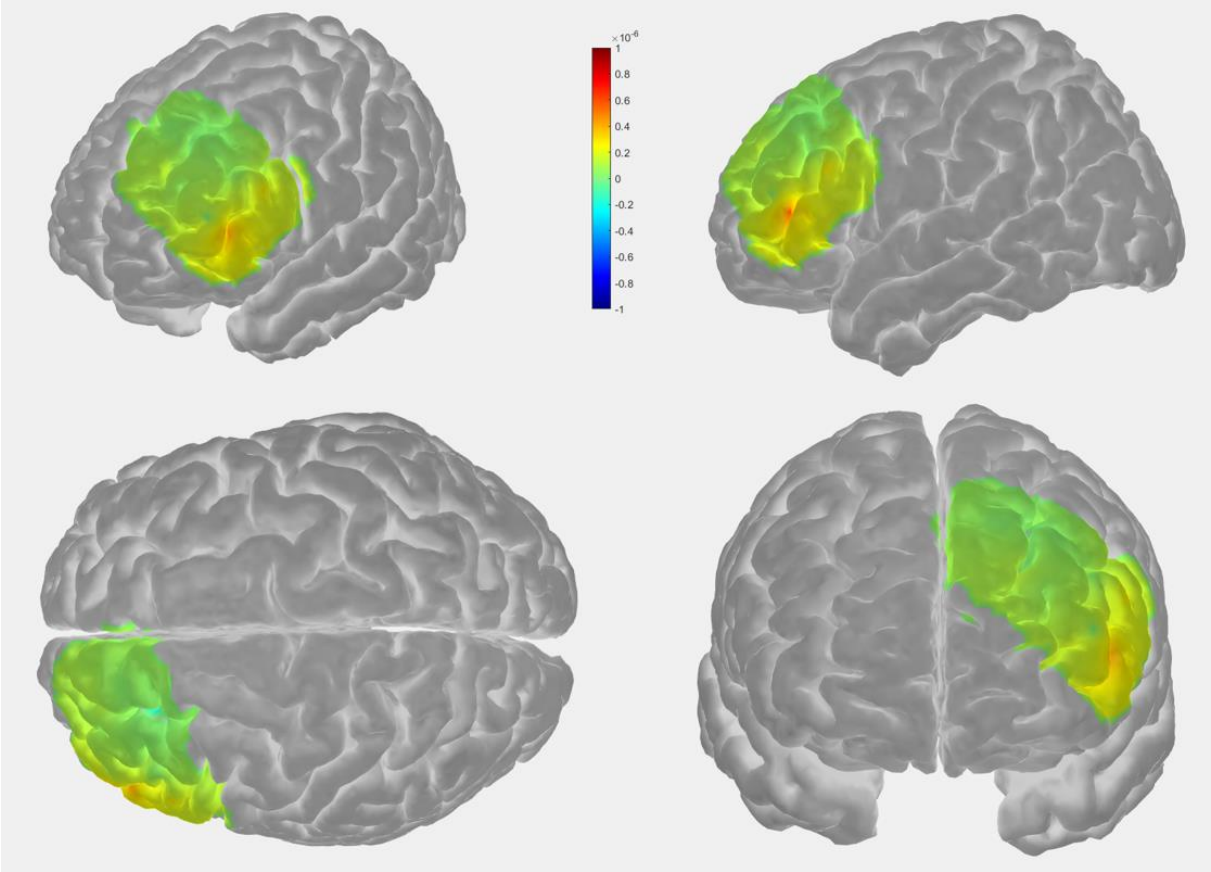

Figure 9. The average activation pattern of the "Negative Accuracy" condition overlaid on a 3D image of the brain.

Does Oxygenated Hemoglobin Concentration and Location Differ Between Occurrence and Accuracy Conditions?

To address the first research question asking whether the level and location of oxygenated hemoglobin in the belief in accuracy conditions differs from the belief in occurrence conditions, paired samples t-tests were conducted to compare the peak beta coefficients across four conditions: positive accuracy, positive occurrence, negative accuracy, and negative occurrence. For channel 1,1 (BA 8; left medial prefrontal cortex), there was a significant difference in the oxygenated hemoglobin concentration for positive accuracy (M = 1.68 x 10^{-7}, SD = 1.25 x 10^{-7}) and positive occurrence (M = 1.41 x 10^{-8}, SD = 2.91 x 10^{-8}); t(195) = -18.53, p = .000; (d = 1.70). There was a significant difference in the oxygenated hemoglobin concentration for positive accuracy (M = 1.68 x 10^{-7}, SD = 1.25 x 10^{-7}) and negative occurrence (M = 3.47 x 10^{-7}, SD = 1.43 x 10^{-7}); t(195) = -11.22, p = .000; (d = 1.33). There was a significant difference in the oxygenated hemoglobin concentration for positive occurrence (M = 1.41 x 10^{-8}, SD = 2.92 x 10^{-8}) and negative accuracy (M = 1.84 x 10^{-7}, SD =6.82 x 10^{-8}); t(195) = -27.91, p = .000; (d = 3.27). There was a significant difference in the oxygenated hemoglobin concentration for negative occurrence (M = 3.47 x 10^{-7}, SD = 1.43 x 10^{-7}) and negative accuracy (M = 1.84 x 10^{-7}, SD = 6.82 x 10^{-8}); t(195) = -21.78, p = .000; (d = 1.45). These findings are shown in Table 3.

Table 3.

Channel 1,1 paired Student's t-tests and Cohen's d effect sizes comparing feedback about accuracy and occurrence.

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	+ Acc	196	1.68×10^{-7}	1.25×10^{-7}	-18.53	195	.000**	1.70
	+ Occ	196	1.41×10^{-8}	2.92×10^{-8}				
Pair 2	+ Acc	196	1.68×10^{-7}	1.25×10^{-7}	-11.22	195	.000**	1.33
	- Occ	196	3.47×10^{-7}	1.43×10^{-7}				
Pair 3	+ Occ	196	1.41×10^{-8}	2.92×10^{-8}	-27.91	195	.000**	3.27
	- Acc	196	1.85×10^{-7}	6.82×10^{-8}				
Pair 4	- Occ	196	3.47×10^{-7}	1.43×10^{-7}	-21.78	195	.000**	1.45
	- Acc	196	1.85×10^{-7}	6.82×10^{-8}				

Abbreviations: + Acc = positive/confirmatory feedback about accuracy; + Occ = positive/confirmatory feedback about occurrence; - Acc = negative/disconfirmatory feedback about accuracy; - Occ = negative/disconfirmatory feedback about occurrence.

For channel 2,1 (BA 9; left dorsolateral prefrontal cortex), there was a significant difference in the oxygenated hemoglobin concentration for positive accuracy ($M = -1.15 \times 10^{-8}$, $SD = 8.49 \times 10^{-8}$) and positive occurrence ($M = 1.76 \times 10^{-7}$, $SD = 9.59 \times 10^{-8}$); t(195) = 18.80, $p = .000$; ($d = 2.07$). There was a significant difference in the oxygenated hemoglobin concentration for positive accuracy ($M = -1.15 \times 10^{-8}$, $SD = 8.49 \times 10^{-8}$) and negative occurrence ($M = 2.03 \times 10^{-7}$, $SD = 1.03 \times 10^{-7}$); t(195) = -43.30, $p = .000$; ($d = 2.23$). There was a significant difference in the oxygenated hemoglobin concentration for

positive occurrence (M = 1.76 x 10^{-7}, SD = 9.59 x 10^{-8}) and negative accuracy (M = 5.84 x 10^{-8}, SD =5.75 x 10^{-8}); t(195) = 15.66, p = .000; (d = 2.57). Finally, there was a significant difference in the oxygenated hemoglobin concentration for negative occurrence (M = 2.03 x 10^{-7}, SD = 1.03 x 10^{-7}) and negative accuracy (M = 5.84 x 10^{-8}, SD =5.75 x 10^{-8}); t(195) = 17.43, p = .000; (d = 1.74). These findings are shown in Table 4.

Table 4.

Channel 2,1 paired Student's t-tests and Cohen's d effect sizes comparing feedback about accuracy and occurrence.

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	+ Acc	196	-1.15 x 10^{-8}	8.49 x 10^{-8}	18.80	195	.000**	2.07
	+ Occ	196	1.76 x 10^{-7}	9.59 x 10^{-8}				
Pair 2	+ Acc	196	-1.15 x 10^{-8}	1.25 x 10^{-7}	-43.30	195	.000**	2.28
	- Occ	196	2.03 x 10^{-7}	1.03 x 10^{-7}				
Pair 3	+ Occ	196	1.76 x 10^{-7}	2.92 x 10^{-8}	15.66	195	.000**	2.57
	- Acc	196	5.84 x 10^{-8}	5.75 x 10^{-8}				
Pair 4	- Occ	196	2.03 x 10^{-7}	1.03 x 10^{-7}	17.43	195	.000**	1.74
	- Acc	196	5.84 x 10^{-8}	5.75 x 10^{-8}				

Abbreviations: + Acc = positive/confirmatory feedback about accuracy; + Occ = positive/confirmatory feedback about occurrence; - Acc = negative/disconfirmatory feedback about accuracy; - Occ = negative/disconfirmatory feedback about occurrence.

For channel 3,1 (BA 9; left dorsolateral prefrontal cortex), there was a significant difference in the oxygenated hemoglobin concentration for positive accuracy (M = -2.18 x 10^{-7}, SD = 8.51 x 10^{-8}) and positive occurrence (M = -2.45 x 10^{-7}, SD = 1.09 x 10^{-7}); t(195) = -2.57, p = .015; (d = 0.30). There was a significant difference in the oxygenated hemoglobin concentration for positive accuracy (M = -2.18 x 10^{-7}, SD = 8.51 x 10^{-8}) and negative occurrence (M = -5.55 x 10^{-8}, SD = 4.83 x 10^{-8}); t(195) = -28.20, p = .000. There was no significant difference in the oxygenated hemoglobin concentration for positive occurrence (M = -2.45 x 10^{-7}, SD = 1.09 x 10^{-7}) and negative accuracy (M = -2.51 x 10^{-7}, SD =8.88 x 10^{-8}); t(195) = 0.49, p = .623. There was a significant difference in the oxygenated hemoglobin concentration for negative occurrence (M = -5.55 x 10^{-8}, SD = 4.83 x 10^{-8}) and negative accuracy (M = -2.51 x 10^{-7}, SD =8.88 x 10^{-8}); t(195) = 20.60, p = .000. These findings are shown in Table 5.

Table 5.

Channel 3,1 paired Student's t-tests and Cohen's d effect sizes comparing feedback about accuracy and occurrence.

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	+ Acc	196	-2.18×10^{-7}	8.51×10^{-8}	-2.57	195	.015*	0.30
	+ Occ	196	-2.45×10^{-7}	9.59×10^{-8}				
Pair 2	+ Acc	196	-2.18×10^{-7}	8.51×10^{-8}	-28.20	195	.000**	2.36
	- Occ	196	-5.55×10^{-8}	4.83×10^{-8}				
Pair 3	+ Occ	196	-2.45×10^{-7}	2.92×10^{-8}	0.49	195	.623	0.09
	- Acc	196	-2.51×10^{-7}	8.88×10^{-8}				
Pair 4	- Occ	196	-5.55×10^{-8}	4.83×10^{-8}	20.60	195	.000**	2.75
	- Acc	196	-2.51×10^{-7}	8.88×10^{-8}				

Abbreviations: + Acc = positive/confirmatory feedback about accuracy; + Occ = positive/confirmatory feedback about occurrence; - Acc = negative/disconfirmatory feedback about accuracy; - Occ = negative/disconfirmatory feedback about occurrence.

For channel 4,1 (BA 10; anterior prefrontal cortex), there was a significant difference in the oxygenated hemoglobin concentration for the positive accuracy condition ($M = 3.38 \times 10^{-7}$, $SD = 1.18 \times 10^{-7}$) and positive occurrence ($M = 5.86 \times 10^{-9}$, $SD = 1.16 \times 10^{-7}$); t(195) = -40.18, $p = .000$; ($d = 2.84$). There was a significant difference in the oxygenated hemoglobin concentration for positive accuracy ($M = 3.38 \times 10^{-7}$, $SD = 1.18 \times 10^{-7}$) and negative occurrence ($M = 9.99 \times 10^{-8}$, $SD = 8.04 \times 10^{-8}$); t(195) = 48.05, $p = .000$; ($d = 2.37$). There was a significant difference in the oxygenated hemoglobin

concentration for positive occurrence (M = 5.86 x 10^{-9}, SD = 1.16 x 10^{-7}) and negative accuracy (M = 8.40 x 10^{-8}, SD =9.65 x 10^{-8}); t(195) = -23.58, p = .000; (d = 1.09). There was not a significant difference in the oxygenated hemoglobin concentration for negative occurrence (M = 9.99 x 10^{-8}, SD = 8.04 x 10^{-8}) and negative accuracy (M = 8.40 x 10^{-8}, SD =9.65 x 10^{-8}); t(195) = 1.76, p = .081; (d = 0.18). These findings are shown in Table 6.

Table 6.

Channel 4,1 paired Student's t-tests and Cohen's d effect sizes comparing feedback about accuracy and occurrence.

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	+ Acc	196	3.38 x 10^{-7}	1.18 x 10^{-7}	-40.18	195	.000**	2.84
	+ Occ	196	5.86 x 10^{-9}	1.16 x 10^{-7}				
Pair 2	+ Acc	196	3.38 x 10^{-7}	1.18 x 10^{-7}	48.05	195	.000**	2.37
	- Occ	196	9.99 x 10^{-8}	8.04 x 10^{-8}				
Pair 3	+ Occ	196	5.86 x 10^{-9}	2.92 x 10^{-8}	-23.58	195	.000**	1.09
	- Acc	196	8.40 x 10^{-8}	9.65 x 10^{-8}				
Pair 4	- Occ	196	9.99 x 10^{-8}	8.04 x 10^{-8}	1.76	195	.081	0.18
	- Acc	196	8.40 x 10^{-8}	9.65 x 10^{-8}				

Abbreviations: + Acc = positive/confirmatory feedback about accuracy; + Occ = positive/confirmatory feedback about occurrence; - Acc = negative/disconfirmatory feedback about accuracy; - Occ = negative/disconfirmatory feedback about occurrence.

For channel 4,2 (BA 10; left anterior prefrontal cortex), there was a significant difference in the oxygenated hemoglobin concentration for the positive accuracy condition (M = 4.22 x 10^{-7}, SD = 9.55 x 10^{-8}) and positive occurrence (M = 2.44 x 10^{-7}, SD = 6.42 x 10^{-8}); t(195) = -45.49, p = .000; (d = 2.19). There was a significant difference in the oxygenated hemoglobin concentration for positive accuracy (M = 4.22^{-7}, SD = 9.55 x 10^{-8}) and negative occurrence (M = -2.08 x 10^{-7}, SD = 2.59 x 10^{-7}); t(195) = 41.17, p = .000; (d = 3.23). There was a significant difference in the oxygenated hemoglobin concentration for positive occurrence (M = 2.44 x 10^{-7}, SD = 6.42 x 10^{-8}) and negative accuracy (M = 2.90 x 10^{-8}, SD =1.11 x 10^{-7}); t(195) = 44.96, p = .000; (d = 2.37). There was a significant difference in the oxygenated hemoglobin concentration for negative occurrence (M = -2.08 x 10^{-7}, SD = 2.59 x 10^{-7}) and negative accuracy (M = 2.90 x 10^{-8}, SD =1.11 x 10^{-7}); t(195) = -17.36, p = .000; (d = 1.60). These findings are shown in Table 7.

Table 7.

Channel 4,2 paired Student's t-tests and Cohen's d effect sizes comparing feedback about accuracy and occurrence.

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	+ Acc	196	4.22×10^{-7}	9.55×10^{-8}	-45.49	195	.000**	2.19
	+ Occ	196	2.44×10^{-7}	6.42×10^{-8}				
Pair 2	+ Acc	196	4.22×10^{-7}	9.55×10^{-8}	41.96	195	.000**	3.23
	- Occ	196	-2.08×10^{-7}	2.59×10^{-7}				
Pair 3	+ Occ	196	2.44×10^{-7}	6.42×10^{-8}	44.96	195	.000**	2.37
	- Acc	196	2.90×10^{-8}	1.11×10^{-7}				
Pair 4	- Occ	196	-2.08×10^{-7}	2.59×10^{-7}	-17.36	195	.000**	1.60
	- Acc	196	2.90×10^{-8}	1.11×10^{-7}				

Abbreviations: + Acc = positive/confirmatory feedback about accuracy; + Occ = positive/confirmatory feedback about occurrence; - Acc = negative/disconfirmatory feedback about accuracy; - Occ = negative/disconfirmatory feedback about occurrence.

For channel 5,2 (BA 45; left inferior frontal gyrus opercularis), there was a significant difference in the oxygenated hemoglobin concentration for the positive accuracy condition ($M = 7.94 \times 10^{-7}$, $SD = 1.78 \times 10^{-7}$) and positive occurrence ($M = 6.03 \times 10^{-7}$, $SD = 1.34 \times 10^{-7}$); t(196) = -12.02, $p = .000$; ($d = 1.43$). There was a significant difference in the oxygenated hemoglobin concentration for positive accuracy ($M = 7.94 \times 10^{-7}$, $SD = 1.78 \times 10^{-7}$) and negative occurrence ($M = -1.81 \times 10^{-7}$, $SD = 1.70 \times 10^{-7}$); t(196) = 63.46, $p = .000$; ($d = 5.60$). There was a significant difference in the oxygenated

hemoglobin concentration for positive occurrence (M = 6.03 x 10^{-7}, SD = 1.34 x 10^{-7}) and negative accuracy (M = 5.75 x 10^{-7}, SD =1.19 x 10^{-7}); t(196) = 5.24, p = .000; (d = 0.29). There was a significant difference in the oxygenated hemoglobin concentration for negative occurrence (M = -1.81 x 10^{-7}, SD = 1.70 x 10^{-7}) and negative accuracy (M = 5.75 x 10^{-7}, SD = 1.19 x 10^{-7}); t(195) = -57.83, p = .000; (d = 5.15). These findings are shown in Table 8.

Table 8.

Channel 5,2 paired Student's t-tests and Cohen's d effect sizes comparing feedback about accuracy and occurrence.

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	+ Acc	196	7.94 x 10^{-7}	1.78 x 10^{-7}	-12.02	195	.000**	1.43
	+ Occ	196	6.03 x 10^{-7}	6.42 x 10^{-8}				
Pair 2	+ Acc	196	7.94 x 10^{-7}	1.78 x 10^{-7}	63.46	195	.000**	5.60
	- Occ	196	-1.81 x 10^{-7}	1.70 x 10^{-7}				
Pair 3	+ Occ	196	6.03 x 10^{-7}	6.42 x 10^{-8}	5.24	195	.000**	0.29
	- Acc	196	5.75 x 10^{-7}	1.19 x 10^{-7}				
Pair 4	- Occ	196	-1.81 x 10^{-7}	1.70 x 10^{-7}	-57.83	195	.000**	5.15
	- Acc	196	5.75 x 10^{-7}	1.19 x 10^{-7}				

Abbreviations: + Acc = positive/confirmatory feedback about accuracy; + Occ = positive/confirmatory feedback about occurrence; - Acc = negative/disconfirmatory feedback about accuracy; - Occ = negative/disconfirmatory feedback about occurrence.

Does Oxygenated Hemoglobin Concentration and Location Differ Between Confirmatory and Disconfirmatory Feedback Conditions?

To address the second research question asking whether the level and location of oxygenated hemoglobin in the confirmatory feedback conditions differs from the disconfirmatory feedback conditions, Student's paired-samples t-tests were conducted to compare the peak beta coefficients across positive accuracy and negative accuracy conditions, and positive occurrence and negative occurrence conditions. For channel 1,1, there was a significant difference in the oxygenated hemoglobin concentration for positive occurrence ($M = 1.41 \times 10^{-8}$, $SD = 2.92 \times 10^{-8}$) and negative occurrence ($M = 3.47 \times 10^{-7}$, $SD = 1.43 \times 10^{-7}$); $t(195) = -31.18$, $p = .000$; ($d = 3.23$). There was no significant difference between positive accuracy ($M = 1.68 \times 10^{-7}$, $SD = 1.25 \times 10^{-7}$) and negative accuracy ($M = 1.85 \times 10^{-7}$, $SD = 6.82 \times 10^{-8}$); $t(195) = -1.57$, $p = .119$; ($d = 0.17$).

Table 9.

Channel 1,1 paired Student's t-tests and Cohen's d effect sizes for confirmatory vs. disconfirmatory social feedback.

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	+ Occ	196	1.41×10^{-8}	2.92×10^{-8}	-31.18	195	.000**	3.23
	- Occ	196	3.47×10^{-7}	1.43×10^{-7}				
Pair 2	+ Acc	196	1.68×10^{-7}	1.25×10^{-7}	-1.57	195	.119	0.17
	- Acc	196	1.85×10^{-7}	6.82×10^{-8}				

Abbreviations: + Acc = positive/confirmatory feedback about accuracy; + Occ = positive/confirmatory feedback about occurrence; - Acc = negative/disconfirmatory feedback about accuracy; - Occ = negative/disconfirmatory feedback about occurrence.

For channel 2,1, there was a significant difference in the oxygenated hemoglobin concentration for positive occurrence ($M = 1.76 \times 10^{-7}$, $SD = 9.60 \times 10^{-8}$) and negative occurrence ($M = 2.03 \times 10^{-7}$, $SD = 1.03 \times 10^{-7}$); t(195) = -2.29, $p = .023$; ($d = 0.27$). There was also a significant difference between positive accuracy ($M = -1.15 \times 10^{-8}$, $SD = 8.50 \times 10^{-8}$) and negative accuracy ($M = 5.84 \times 10^{-8}$, $SD = 5.75 \times 10^{-8}$); t(195) = -14.47, $p = .000$; ($d = 0.96$). These findings are shown in Table 10.

Table 10.

Channel 2,1 paired Student's t-tests and Cohen's d effect sizes for confirmatory vs. disconfirmatory social feedback.

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	+ Occ	196	1.76×10^{-7}	9.60×10^{-8}	-2.29	195	.023*	0.27
	- Occ	196	2.03×10^{-7}	1.03×10^{-7}				
Pair 2	+ Acc	196	-1.15×10^{-8}	8.50×10^{-8}	-14.47	195	.000**	0.96
	- Acc	196	5.84×10^{-8}	5.75×10^{-8}				

Abbreviations: + Acc = positive/confirmatory feedback about accuracy; + Occ = positive/confirmatory feedback about occurrence; - Acc = negative/disconfirmatory feedback about accuracy; - Occ = negative/disconfirmatory feedback about occurrence.

For channel 3,1, there was a significant difference in the oxygenated hemoglobin concentration for positive occurrence ($M = -2.45 \times 10^{-7}$, $SD = 1.10 \times 10^{-7}$) and negative occurrence ($M = -5.54 \times 10^{-8}$, $SD = 4.83 \times 10^{-8}$); t(195) = -22.36, $p = .000$; ($d = 2.23$). There was also a significant difference between positive accuracy ($M = -2.18 \times 10^{-7}$, $SD = 8.51 \times 10^{-8}$) and negative accuracy ($M = -2.50 \times 10^{-7}$, $SD = 8.88 \times 10^{-8}$); t(195) = 3.58, $p = .000$; ($d = 0.37$). These findings are shown in Table 11.

Table 11.

Channel 3,1 paired Student's t-tests and Cohen's d effect sizes for confirmatory vs. disconfirmatory social feedback.

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	+ Occ	196	-2.45 x10^{-7}	1.10 x 10^{-7}	-22.36	195	.000**	2.23
	- Occ	196	-5.54 x 10^{-8}	4.83 x 10^{-8}				
Pair 2	+ Acc	196	-2.18 x 10^{-7}	8.51 x 10^{-8}	3.58	195	.000**	0.37
	- Acc	196	-2.50 x 10^{-7}	8.88 x 10^{-8}				

Abbreviations: + Acc = positive/confirmatory feedback about accuracy; + Occ = positive/confirmatory feedback about occurrence; - Acc = negative/disconfirmatory feedback about accuracy; - Occ = negative/disconfirmatory feedback about occurrence.

For channel 4,1, there was a significant difference in the oxygenated hemoglobin concentration for positive occurrence (M = 5.86 x 10^{-9}, SD = 1.16 x 10^{-7}) and negative occurrence (M = 9.99 x 10^{-8}, SD = 8.04 x 10^{-8}); t(195) = -10.14, p = .000; (d = 0.94). There was also a significant difference between positive accuracy (M = 3.38 x 10^{-7}, SD = 1.18 x 10^{-7}) and negative accuracy (M = 8.40 x 10^{-8}, SD = 9.65 x 10^{-8}); t(195) = 29.01, p = .000; (d = 2.36). These findings are shown in Table 12.

Table 12.

Channel 4,1 paired Student's t-tests and Cohen's d effect sizes for confirmatory vs. disconfirmatory social feedback.

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	+ Occ	196	5.86×10^{-9}	1.16×10^{-7}	-10.14	195	.000**	0.94
	- Occ	196	9.99×10^{-8}	8.04×10^{-8}				
Pair 2	+ Acc	196	3.38×10^{-7}	1.18×10^{-7}	29.01	195	.000**	2.36
	- Acc	196	8.40×10^{-8}	9.65×10^{-8}				

Abbreviations: + Acc = positive/confirmatory feedback about accuracy; + Occ = positive/confirmatory feedback about occurrence; - Acc = negative/disconfirmatory feedback about accuracy; - Occ = negative/disconfirmatory feedback about occurrence.

For channel 4,2, there was a significant difference in the oxygenated hemoglobin concentration for positive occurrence ($M = 2.45 \times 10^{-7}$, $SD = 6.42 \times 10^{-8}$) and negative occurrence ($M = -2.08 \times 10^{-7}$, $SD = 2.59 \times 10^{-7}$); t(195) = 31.18, $p = .000$; ($d = 0.94$). There was also a significant difference between positive accuracy ($M = 4.22 \times 10^{-7}$, $SD = 9.55 \times 10^{-9}$) and negative accuracy ($M = 2.90 \times 10^{-8}$, $SD = 1.11 \times 10^{-7}$); t(195) = 105.76, $p = .000$; ($d = 2.36$). These findings are shown in Table 13.

Table 13.

Channel 4,2 paired Student's t-tests and Cohen's d effect sizes for confirmatory vs. disconfirmatory social feedback.

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	+ Occ	196	5.86×10^{-9}	1.16×10^{-7}	-10.14	195	.000**	0.94
	- Occ	196	9.99×10^{-8}	8.04×10^{-8}				
Pair 2	+ Acc	196	3.38×10^{-7}	1.18×10^{-7}	29.01	195	.000**	2.36
	- Acc	196	8.40×10^{-8}	9.65×10^{-8}				

Abbreviations: + Acc = positive/confirmatory feedback about accuracy; + Occ = positive/confirmatory feedback about occurrence; - Acc = negative/disconfirmatory feedback about accuracy; - Occ = negative/disconfirmatory feedback about occurrence.

For channel 5,2, there was a significant difference in the oxygenated hemoglobin concentration for positive occurrence ($M = 6.03 \times 10^{-7}$, $SD = 1.34 \times 10^{-7}$) and negative occurrence ($M = -1.81 \times 10^{-7}$, $SD = 1.69 \times 10^{-7}$); t(195) = 65.69, $p = .000$; ($d = 5.14$). There was also a significant difference between positive accuracy ($M = 7.94 \times 10^{-7}$, $SD = 1.78 \times 10^{-7}$) and negative accuracy ($M = 5.75 \times 10^{-7}$, $SD = 1.19 \times 10^{-7}$); t(195) = 13.17, $p = .000$; ($d = 1.45$). These findings are shown in Table 14.

Table 14.

Channel 5,2 paired Student's t-tests and Cohen's d effect sizes for confirmatory vs. disconfirmatory social feedback.

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	+ Occ	196	6.03×10^{-7}	1.34×10^{-7}	65.68	195	.000**	5.14
	- Occ	196	-1.81×10^{-7}	1.69×10^{-7}				
Pair 2	+ Acc	196	7.94×10^{-7}	1.78×10^{-7}	13.17	195	.000**	1.45
	- Acc	196	5.75×10^{-7}	1.19×10^{-7}				

Abbreviations: + Acc = positive/confirmatory feedback about accuracy; + Occ = positive/confirmatory feedback about occurrence; - Acc = negative/disconfirmatory feedback about accuracy; - Occ = negative/disconfirmatory feedback about occurrence.

Analysis of Belief in Occurrence Behavioural Data

Belief in occurrence scores for the two rating items are presented in Table 15 and Figure 10. There were no statistically significant differences between the pre-feedback belief in occurrence ratings across the five within-subjects' feedback conditions. Ratings for control items significantly changed upon re-rating. Mean difference = .34 [95% CI, .03, .65]; (d = .37).

When participants were given positive feedback about memory occurrence, belief in occurrence scores increased by 0.34 points on the scale [95% CI, -.05, .73]; (d = .35). When they were given positive feedback about memory accuracy, belief in occurrence scores increased by 0.50 points on the scale [95% CI, .18, .82]; (d = .47). When they were given negative feedback about memory occurrence, belief in occurrence scores decreased

by 1.54 points on the scale [95% CI, -2.22, -.87]; (*d* = .80). When they were given negative feedback about memory accuracy, belief in occurrence scores increased by 0.22 points [95% CI, -.04, .48]; (*d* = .20). Change scores for both belief in accuracy and belief in occurrence are shown in Figure 11.

Table 15.

Pre- and post-social feedback belief in occurrence scores.

Type of Feedback	Average Belief in Occurrence Scores Before Feedback [95% CI]	Average Belief in Occurrence Scores After Feedback [95% CI]	Average Change [95% CI]	Effect Size (Cohen's d)
Control	6.29 [5.97-6.62]	6.63 [6.32-6.95]	**.34* [.03, -.65]**	**.37**
+ Occurrence	6.25 [5.91-6.59]	6.59 [6.24-6.93]	.34 [-.05, .73]	.35
+ Accuracy	6.21 [5.84-6.57]	6.71 [6.32-7.09]	**.50* [.18, .82]**	**.47**
- Occurrence	6.26 [5.83-6.70]	4.72 [3.86-5.58]	**-1.54* [-2.22, -.87]**	**.80**
- Accuracy	6.16 [5.79-6.54]	6.38 [6.01-6.76]	.22 [-.04, .48]	.20

Note. Feedback types are denoted by + (positive) or – (negative). Significance is bolded and denoted by an asterisk (*).

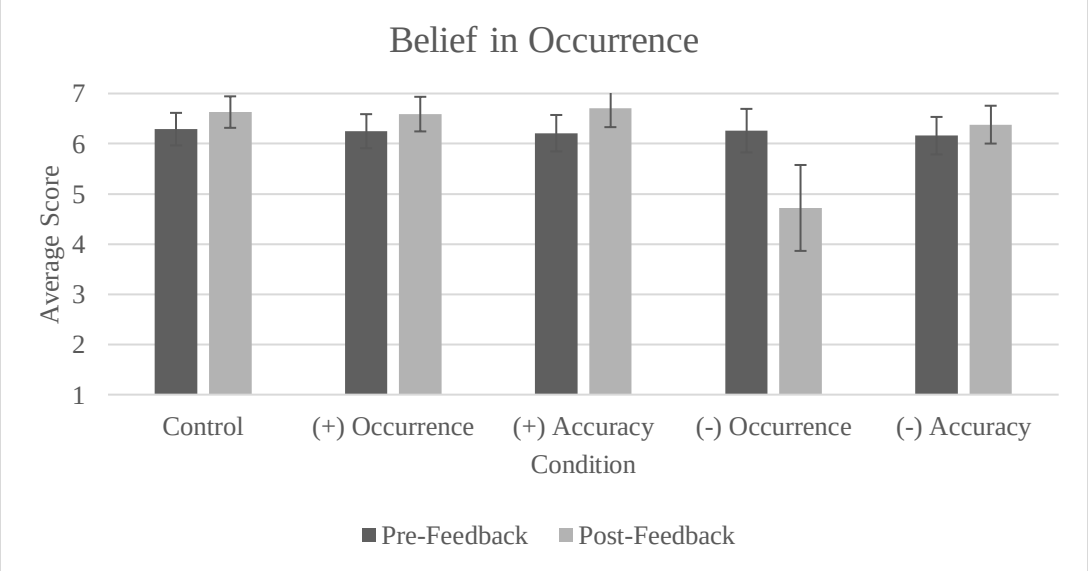

Figure 10. Graph depicting belief in occurrence average rating scores before and after receiving each type of social feedback with 95% confidence intervals.

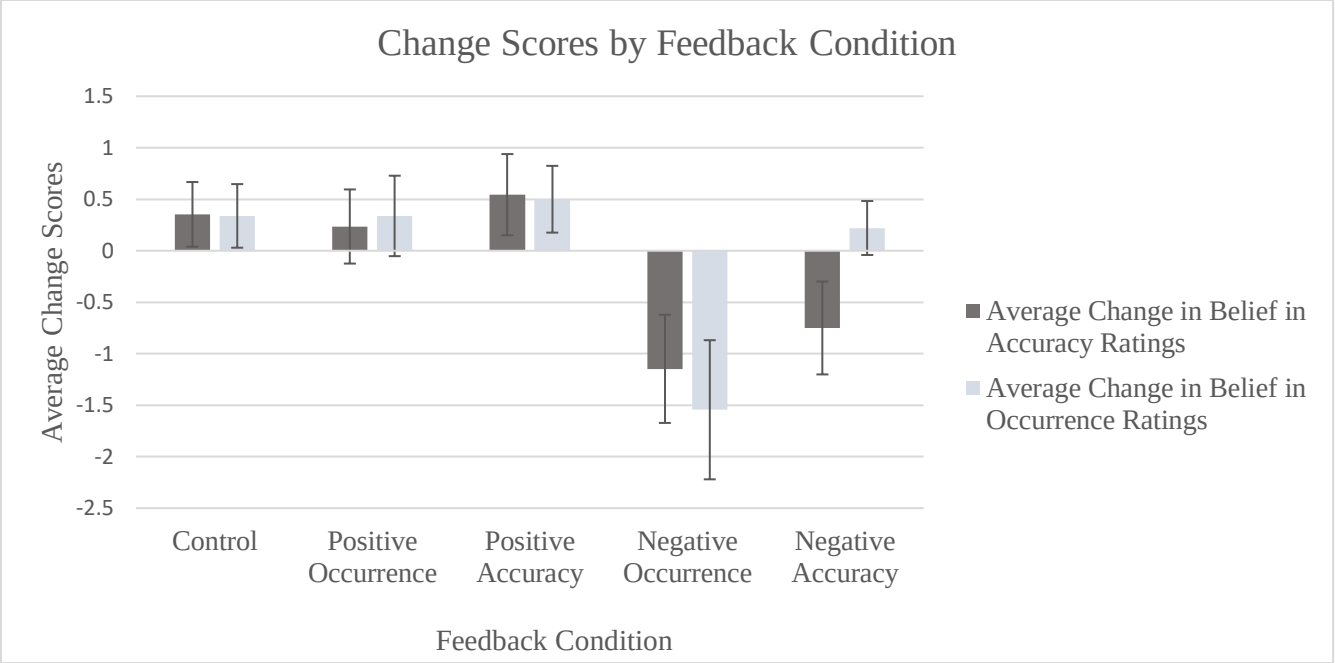

Figure 11. Graph depicting belief in occurrence and belief in accuracy change scores (post-feedback - pre-feedback) and 95% confidence intervals.

Analysis of Belief in Accuracy Behavioural Data

Belief in accuracy scores for the two rating items are presented in Table 16 and Figure 12. There were no statistically significant differences between the pre-feedback belief in accuracy ratings across the five within-subjects' feedback conditions. Ratings for control items significantly changed upon re-rating. Mean difference = .35 [95% CI, .04, .67]; (*d* = .27).

When participants were given positive feedback about memory occurrence, belief in accuracy scores increased by 0.24 points on the scale [95% CI, -.12, .60]; (*d* = .35). When they were given positive feedback about memory accuracy, belief in accuracy scores increased by 0.54 points on the scale [95% CI, .15, .94]; (*d* = .44). When they were given negative feedback about memory occurrence, belief in accuracy scores decreased

by 1.15 points on the scale [95% CI, -1.67, -.62]; (d = .63). When they were given negative feedback about memory accuracy, belief in accuracy scores decreased by 0.75 points [95% CI, -1.20, -.29]; (d = .53). Change scores for both belief in accuracy and belief in occurrence are shown in Figure 11.

Table 16.

Pre- and post-social feedback belief in accuracy scores.

Type of Feedback	Average Belief in Accuracy Scores Before Feedback	Average Belief in Accuracy Scores After Feedback	Average Change [95% CI]	Effect Size (Cohen's d)
Control	5.27 [4.77-5.75]	5.62 [5.21-6.03]	**.35* [.04, .67]**	**.27**
+ Occurrence	5.20 [4.73-5.68]	5.44 [4.97-5.92]	.24 [-.12, .60]	.17
+ Accuracy	5.32 [4.87-5.78]	5.86 [5.45-6.28]	**.54* [.15, .94]**	**.44**
- Occurrence	5.25 [4.68-5.82]	4.10 [3.40-4.80]	**-1.15* [-1.67, -.62]**	**.63**
- Accuracy	5.15 [4.63-5.67]	4.40 [3.93-4.86]	**-.75* [-1.20, -.29]**	**.53**

Note. Feedback types are denoted by + (positive) or – (negative). Significance is bolded and denoted by an asterisk (*).

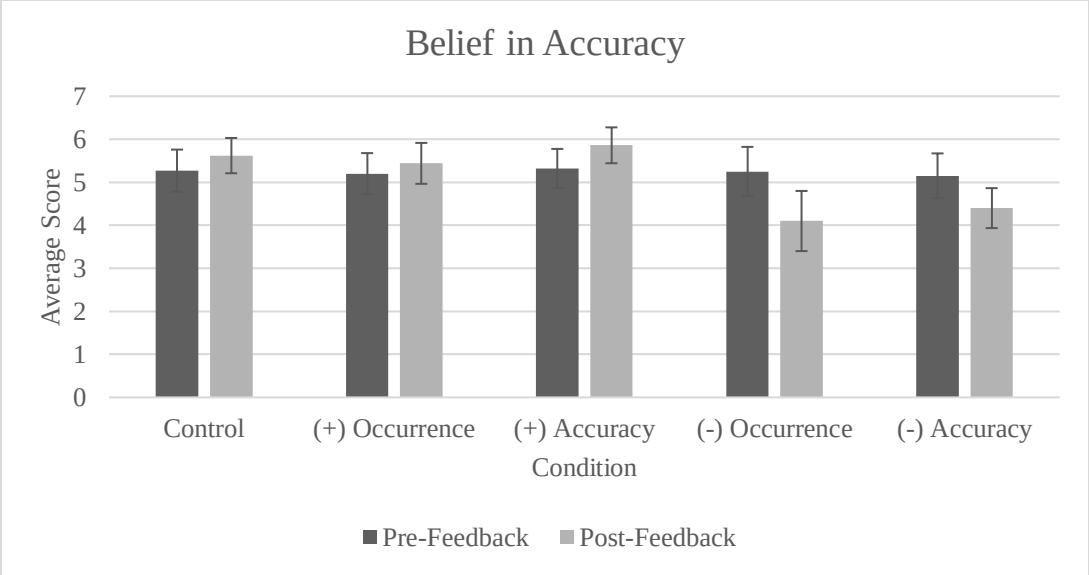

Figure 12. Graph depicting belief in accuracy average rating scores before and after receiving each type of social feedback with 95% confidence intervals.

Analysis of Relinquishment, Partial Relinquishment, and Non-Relinquishment of Memory

Behavioural Analysis

All 17 participants were separated into relinquishment type categories: 6 were categorized as relinquishers, 5 were categorized as non-relinquishers, and 6 were categorized as partial relinquishers. Partial relinquishers were further sub-divided into "relinquished belief in occurrence", "relinquished belief in accuracy", or "unclear relinquishment of belief in accuracy" (see Table 17).

Table 17.

Participant relinquishment types and sub-types

	Number of Participants	Participant Codes	Partial Relinquisher Sub-Type	Number of Participants	Participant Codes
Relinquisher	6	08.B2; 17.A1; 18.B1; 19.A2; 24.B2; 25.A1.			
Partial Relinquisher	6	06.B1; 14.B1; 16.B2; 20.B2; 21.A1; 22.B1.	Relinquished Belief in Occurrence	1	14.B1.
			Relinquished Belief in Accuracy	2	20.B2; 22.B1.
			Unclear Relinquishment of Belief in Accuracy	3	06.B1; 16.B2; 21.A1.
Non-Relinquisher	5	02.B1; 04.B2; 11.A2; 12.B2; 23.A2.			

Table 18 denotes relinquishment type and response to each instance of social challenge. In order to be placed into the "relinquisher" category, the participant had to show a decrease from their pre-feedback score after every instance of disconfirmatory social feedback across the four instances of negative feedback, with a decrease being defined as a change of -0.5 points or more for this study. In order to be placed in the "non-relinquisher" category, the participant had to show either no change or an increase in their score after every instance of disconfirmatory social feedback on the four instances of negative feedback.

Table 18.

Breakdown of participant relinquishment type and instance of disconfirmatory social feedback.

Participant	Occurrence Challenge 1	Occurrence Challenge 2	Accuracy Challenge 1	Accuracy Challenge 2	Relinquishment Type	If partial, subtype?
2.B1	No	No	No	No	Non-Relinquisher	
4.B2	No	No	No	No	Non-Relinquisher	
6.B1	Yes	Yes	Yes	No	Partial Relinquisher	Unclear Belief in Accuracy
8.B2	Yes	Yes	Yes	Yes	Relinquisher	
11.A2	No	No	No	No	Non-Relinquisher	
12.B2	No	No	No	No	Non-Relinquisher	
14.B1	Yes	Yes	No	No	Partial Relinquisher	Relinquished Belief in Occurrence
16.B2	Yes	Yes	No	Yes	Partial Relinquisher	Unclear Belief in Accuracy
17.A1	Yes	Yes	Yes	Yes	Relinquisher	
18.B1	Yes	Yes	Yes	Yes	Relinquisher	
19.A2	Yes	Yes	Yes	Yes	Relinquisher	
20.B2	No	No	Yes	Yes	Partial Relinquisher	Relinquished Belief in Accuracy
21.A1	Yes	Yes	No	Yes	Partial Relinquisher	Unclear Belief in Accuracy
22.B1	No	No	Yes	Yes	Partial Relinquisher	Relinquished Belief in Accuracy
23.A2	No	No	No	No	Non-Relinquisher	
24.B2	Yes	Yes	Yes	Yes	Relinquisher	
25.A1	Yes	Yes	Yes	Yes	Relinquisher	

Note. Each participant was challenged for their belief in their memory occurrence and memory accuracy two times (as shown in columns 2-5). Average belief in occurrence and belief in accuracy change scores were used to denote each participant as "yes" or "no" in each row. Participants had to show at least a 0.5-point decrease on belief in accuracy items when challenged about memory accuracy or at least a 0.5-point decrease on belief in occurrence items when challenged about memory occurrence to be deemed as a relinquisher. Non-relinquishers had to show no change across all instances of challenge.

Partial relinquishers showed either relinquishment of only belief in accuracy and not belief in occurrence ("relinquished belief in accuracy" subtype), relinquishment of belief in occurrence and not belief in accuracy ("relinquished belief in occurrence" subtype), or an unclear pattern of relinquishment, whereby they relinquished belief in accuracy on one instance of challenge but not on the other ("unclear belief in accuracy" subtype).

Analysis of Exploratory fNIRS Findings

To address the exploratory portion of the second research question assessing whether the level and location of oxygenated hemoglobin differs between participants who relinquish their belief in their memory and participants who maintain their belief in their memory, independent-samples t-tests were conducted to compare the peak beta coefficients across the three different relinquishment types: relinquisher, partial relinquisher, and non-relinquisher. These differences are compared for both types of disconfirmatory feedback (occurrence and accuracy), across each channel.

For channel 1,1, there was a significant difference in the oxygenated hemoglobin concentration between participants who received disconfirmatory feedback about the *occurrence* of their memory and relinquished belief ($M = 9.44 \times 10^{-7}$, $SD = 1.50 \times 10^{-7}$) and those who only partially relinquished belief ($M = 6.72 \times 10^{-8}$, $SD = 9.24 \times 10^{-8}$); $t(390) = 69.58$, $p = .000$; ($d = 7.04$). There was also a significant difference between those who relinquished belief ($M = 9.44 \times 10^{-7}$, $SD = 1.50 \times 10^{-7}$) and did not relinquish belief ($M = -1.98 \times 10^{-7}$, $SD = 1.02 \times 10^{-7}$); $t(390) = 87.91$, $p = .000$; ($d = 8.90$). Finally, there was also a significant difference between participants who partially relinquished belief

(M = 6.72 x 10^{-8}, SD = 9.24 x 10^{-8}) and those who did not relinquish belief (M = -1.98 x 10^{-7}, SD = 1.02 x 10^{-7}); t(390) = 26.88; (d = 2.73). These findings are shown in Table 19.

Table 19.

Channel 1,1 – Independent samples t-tests and Cohen's d for deceptive feedback about memory occurrence

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	Relinquisher	196	9.44 x 10^{-7}	1.50 x 10^{-7}	69.58	390	.000**	7.04
	Partial Relinquisher	196	6.72 x 10^{-8}	9.24 x 10^{-8}				
Pair 2	Relinquisher	196	9.44 x 10^{-7}	1.50 x 10^{-7}	87.91	390	.000**	8.90
	Non-Relinquisher	196	-1.98 x 10^{-7}	1.02 x 10^{-7}				
Pair 3	Partial Relinquisher	196	6.72 x 10^{-8}	9.24 x 10^{-8}	26.88	390	.000**	2.73
	Non-Relinquisher	196	-1.98 x 10^{-7}	1.02 x 10^{-7}				

When looking at channel 1,1, there was a significant difference in the oxygenated hemoglobin concentration between participants who received disconfirmatory feedback about the *accuracy* of their memory and relinquished belief (M = -5.36 x 10^{-8}, SD = 3.98 x 10^{-8}) and those who only partially relinquished belief (M = 4.30 x 10^{-7}, SD = 4.34 x 10^{-8}); t(390) = -115.06, p = .000; (d = 11.63). There was also a significant difference between those who relinquished belief (M = -5.36 x 10^{-8}, SD = 3.98 x 10^{-8}) and did not relinquish belief (M = 2.20 x 10^{-7}, SD = 1.52 x 10^{-7}); t(390) = -24.43, p = .000; (d = 2.46). Finally, there was also a significant difference between participants who partially relinquished belief (M = 4.30 x 10^{-7}, SD = 4.34 x 10^{-8}) and those who did not relinquish belief (M = 2.20 x 10^{-7}, SD = 1.52 x 10^{-7}); t(390) = 18.61; (d = 1.88). These findings are shown in Table 20.

Table 20.

Channel 1,1 – Independent samples t-tests and Cohen's d for deceptive feedback about memory accuracy

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	Relinquisher	196	-5.36×10^{-8}	3.98×10^{-8}	-115.06	390	.000**	11.63
	Partial Relinquisher	196	4.30×10^{-7}	4.34×10^{-8}				
Pair 2	Relinquisher	196	-5.36×10^{-8}	3.98×10^{-8}	-24.43	390	.000**	2.46
	Non-Relinquisher	196	2.20×10^{-7}	1.52×10^{-7}				
Pair 3	Partial Relinquisher	196	4.30×10^{-7}	4.33×10^{-8}	18.61	390	.000**	1.88
	Non-Relinquisher	196	2.20×10^{-7}	1.52×10^{-7}				

For channel 2,1, there was a significant difference in the oxygenated hemoglobin concentration between participants who received disconfirmatory feedback about the *occurrence* of their memory and relinquished belief ($M = 2.85 \times 10^{-7}$, $SD = 2.90 \times 10^{-7}$) and those who only partially relinquished belief ($M = -1.49 \times 10^{-6}$, $SD = 1.19 \times 10^{-7}$); t(390) = 79.52, $p = .000$; ($d = 6.02$). There was also a significant difference between those who relinquished belief ($M = 2.85 \times 10^{-7}$, $SD = 2.90 \times 10^{-7}$) and did not relinquish belief ($M = -2.08 \times 10^{-7}$, $SD = 1.05 \times 10^{-7}$); t(390) = 22.34, $p = .000$; ($d = 2.26$). Finally, there was also a significant difference between participants who partially relinquished belief ($M = -1.49 \times 10^{-6}$, $SD = 1.19 \times 10^{-7}$) and those who did not relinquish belief ($M = -2.08 \times 10^{-7}$, $SD = 1.05 \times 10^{-7}$); t(390) = -114.02; ($d = 7.50$). These findings are shown in Table 21.

Table 21.

Channel 2,1 – Independent samples t-tests and Cohen's d for deceptive feedback about memory occurrence

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	Relinquisher	196	2.85×10^{-7}	2.90×10^{-7}	79.52	390	.000**	6.02
	Partial Relinquisher	196	-1.49×10^{-6}	1.19×10^{-7}				
Pair 2	Relinquisher	196	2.85×10^{-7}	2.90×10^{-7}	22.34	390	.000**	2.26
	Non-Relinquisher	196	-2.08×10^{-7}	1.05×10^{-7}				
Pair 3	Partial Relinquisher	196	-1.49×10^{-6}	1.19×10^{-7}	-114.02	390	.000**	7.50
	Non-Relinquisher	196	-2.08×10^{-7}	1.05×10^{-7}				

Also for channel 2,1, there was a significant difference in the oxygenated hemoglobin concentration between participants who received disconfirmatory feedback about the *accuracy* of their memory and relinquished belief ($M = 1.19 \times 10^{-6}$, $SD = 6.50 \times 10^{-8}$) and those who only partially relinquished belief ($M = 5.45 \times 10^{-7}$, $SD = 1.09 \times 10^{-7}$); t(390) = 70.88, $p = .000$; ($d = 7.19$). There was also a significant difference between those who relinquished belief ($M = 1.19 \times 10^{-6}$, $SD = 6.50 \times 10^{-8}$) and did not relinquish belief ($M = 1.44 \times 10^{-8}$, $SD = 1.55 \times 10^{-7}$); t(390) = 97.79, $p = .000$; ($d = 9.89$). Finally, there was also a significant difference between participants who partially relinquished belief ($M = 5.45 \times 10^{-7}$, $SD = 1.09 \times 10^{-7}$) and those who did not relinquish belief ($M = 1.44 \times 10^{-8}$, $SD = 1.55 \times 10^{-7}$); t(390) = 39.16; ($d = 3.96$). These findings are shown in Table 22.

Table 22.

Channel 2,1 – Independent samples t-tests and Cohen's d for deceptive feedback about memory accuracy

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	Relinquisher	196	1.19×10^{-6}	6.50×10^{-8}	70.88	390	.000**	7.19
	Partial Relinquisher	196	5.45×10^{-7}	1.09×10^{-7}				
Pair 2	Relinquisher	196	1.19×10^{-6}	6.50×10^{-8}	97.79	390	.000**	9.89
	Non-Relinquisher	196	1.44×10^{-8}	1.55×10^{-7}				
Pair 3	Partial Relinquisher	196	5.45×10^{-7}	1.09×10^{-7}	39.16	390	.000**	3.96
	Non-Relinquisher	196	1.44×10^{-8}	1.55×10^{-7}				

For channel 3,1, there was a significant difference in the oxygenated hemoglobin concentration between participants who received disconfirmatory feedback about the *occurrence* of their memory and relinquished belief ($M = 1.26 \times 10^{-7}$, $SD = 6.95 \times 10^{-8}$) and those who only partially relinquished belief ($M = 4.69 \times 10^{-8}$, $SD = 1.03 \times 10^{-7}$); t(390) = 8.87, $p = .000$; ($d = 0.90$). There was also a significant difference between those who relinquished belief ($M = 1.26 \times 10^{-7}$, $SD = 6.95 \times 10^{-8}$) and did not relinquish belief ($M = -2.24 \times 10^{-7}$, $SD = 3.38 \times 10^{-8}$); t(390) = 63.42, $p = .000$; ($d = 6.41$). Finally, there was also a significant difference between participants who partially relinquished belief ($M = 4.69 \times 10^{-8}$, $SD = 1.03 \times 10^{-7}$) and those who did not relinquish belief ($M = -2.24 \times 10^{-7}$, $SD = 3.38 \times 10^{-8}$); t(390) = 35.03; ($d = 3.53$). These findings are shown in Table 23.

Table 23.

Channel 3,1 – Independent samples t-tests and Cohen's d for deceptive feedback about memory occurrence

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	Relinquisher	196	1.26×10^{-7}	6.95×10^{-8}	8.87	390	.000**	0.9
	Partial Relinquisher	196	4.69×10^{-8}	1.03×10^{-7}				
Pair 2	Relinquisher	196	1.26×10^{-7}	6.95×10^{-8}	63.42	390	.000**	6.41
	Non-Relinquisher	196	-2.24×10^{-7}	3.38×10^{-8}				
Pair 3	Partial Relinquisher	196	4.70×10^{-8}	1.03×10^{-7}	35.03	390	.000**	3.53
	Non-Relinquisher	196	-2.24×10^{-7}	3.38×10^{-8}				

Again, when looking at channel 3,1, there was a significant difference in the oxygenated hemoglobin concentration between participants who received disconfirmatory feedback about the *accuracy* of their memory and relinquished belief ($M = -1.69 \times 10^{-7}$, $SD = 1.76 \times 10^{-7}$) and those who only partially relinquished belief ($M = 2.27 \times 10^{-7}$, $SD = 8.15 \times 10^{-8}$); t(390) = -28.68, $p = .000$; ($d = 2.89$). There was also a significant difference between those who relinquished belief ($M = -1.69 \times 10^{-7}$, $SD = 1.76 \times 10^{-7}$) and did not relinquish belief ($M = -1.34 \times 10^{-8}$, $SD = 1.59 \times 10^{-7}$); t(390) = -9.21, $p = .000$; ($d = 0.93$). Finally, there was also a significant difference between participants who partially relinquished belief ($M = 2.27 \times 10^{-7}$, $SD = 8.15 \times 10^{-8}$) and those who did not relinquish belief ($M = -1.34 \times 10^{-8}$, $SD = 1.59 \times 10^{-7}$); t(390) = 18.87; ($d = 1.90$). These findings are shown in Table 24.

Table 24.

Channel 3,1 – Independent samples t-tests and Cohen's d for deceptive feedback about memory accuracy

		Sample Size (n)	Mean	Std. Deviation	T	df	Sig. (2-tailed)	Cohen's d
Pair 1	Relinquisher	196	-1.69×10^{-7}	1.76×10^{-7}	-28.68	390	.000**	2.89
	Partial Relinquisher	196	2.27×10^{-7}	8.15×10^{-8}				
Pair 2	Relinquisher	196	-1.69×10^{-7}	1.76×10^{-7}	-9.21	390	.000**	0.93
	Non-Relinquisher	196	-1.34×10^{-8}	1.59×10^{-7}				
Pair 3	Partial Relinquisher	196	2.27×10^{-7}	8.15×10^{-8}	18.87	390	.000**	1.90
	Non-Relinquisher	196	-1.34×10^{-8}	1.59×10^{-7}				

For channel 4,1, there was a significant difference in the oxygenated hemoglobin concentration between participants who received disconfirmatory feedback about the *occurrence* of their memory and relinquished belief ($M = 2.91 \times 10^{-7}$, $SD = 2.90 \times 10^{-7}$) and those who only partially relinquished belief ($M = -2.57 \times 10^{-7}$, $SD = 1.02 \times 10^{-7}$); t(390) = 24.99, $p = .000$; ($d = 2.52$). There was also a significant difference between those who relinquished belief ($M = 2.91 \times 10^{-7}$, $SD = 2.90 \times 10^{-7}$) and did not relinquish belief ($M = -5.24 \times 10^{-7}$, $SD = 9.57 \times 10^{-8}$); t(390) = 37.37, $p = .000$; ($d = 3.78$). Finally, there was also a significant difference between participants who partially relinquished belief ($M = -2.57 \times 10^{-7}$, $SD = 1.02 \times 10^{-7}$) and those who did not relinquish belief ($M = -5.24 \times 10^{-7}$, $SD = 9.57 \times 10^{-8}$); t(390) = 26.68; ($d = 2.71$). These findings are shown in Table 25.

Table 25.

Channel 4,1 – Independent samples t-tests and Cohen's d for deceptive feedback about memory occurrence

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	Relinquisher	196	2.91×10^{-7}	2.90×10^{-7}	24.99	390	.000**	2.52
	Partial Relinquisher	196	-2.57×10^{-7}	1.02×10^{-7}				
Pair 2	Relinquisher	196	2.91×10^{-7}	2.90×10^{-7}	37.37	390	.000**	3.78
	Non-Relinquisher	196	-5.24×10^{-7}	9.57×10^{-8}				
Pair 3	Partial Relinquisher	196	-2.57×10^{-7}	1.01×10^{-7}	26.68	390	.000**	2.71
	Non-Relinquisher	196	-5.24×10^{-7}	9.56×10^{-8}				

Again, when looking at channel 4,1, there was a significant difference between participants who partially relinquished belief ($M = -9.71 \times 10^{-8}$, $SD = 1.01 \times 10^{-7}$) and those who did not relinquish belief ($M = 3.78 \times 10^{-8}$, $SD = 2.02 \times 10^{-7}$); t(390) = -8.37; (d = 0.85). Unfortunately, due to poor signal quality, channel 4,1's results were unavailable for the "relinquisher" group. These findings are shown in Table 26.

Table 26.

Channel 4,1 – Independent samples t-tests and Cohen's d for deceptive feedback about memory accuracy

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	Relinquisher	-	-	-	-	-	-	
	Partial Relinquisher	196	-9.71×10^{-8}	1.01×10^{-7}				
Pair 2	Relinquisher	-	-	-	-	-	-	
	Non-Relinquisher	196	3.78×10^{-8}	2.02×10^{-7}				
Pair 3	Partial Relinquisher	196	-9.71×10^{-8}	1.01×10^{-7}	-8.37	390	.000**	0.85
	Non-Relinquisher	196	3.78×10^{-8}	2.02×10^{-7}				

For channel 4,2, there was no significant difference between participants who partially relinquished belief when given disconfirmatory feedback about memory occurrence ($M = 2.69 \times 10^{-7}$, $SD = 3.07 \times 10^{-7}$) and those who did not relinquish belief ($M = 2.82 \times 10^{-7}$, $SD = 5.09 \times 10^{-8}$); t(390) = -0.59; (d = 1.10). Unfortunately, due to poor signal quality, channel 4,2's results were unavailable for the "relinquisher" group. These findings are shown in Table 27.

Table 27.

Channel 4,2 – Independent samples t-tests and Cohen's d for deceptive feedback about memory occurrence

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	Relinquisher	-	-	-	-	-	-	
	Partial Relinquisher	196	2.69×10^{-7}	3.07×10^{-7}				
Pair 2	Relinquisher	-	-	-	-	-	-	
	Non-Relinquisher	196	2.82×10^{-7}	5.09×10^{-8}				
Pair 3	Partial Relinquisher	196	2.69×10^{-7}	3.07×10^{-7}	-.59	390	.553	1.10
	Non-Relinquisher	196	2.82×10^{-8}	5.09×10^{-8}				

Again, when looking at channel 4,2, there was a significant difference between participants who partially relinquished belief when given disconfirmatory feedback about memory *accuracy* ($M = 1.47 \times 10^{-8}$, $SD = 1.47 \times 10^{-7}$) and those who did not relinquish belief ($M = 6.54 \times 10^{-8}$, $SD = 1.76 \times 10^{-7}$); t(390) = -3.10, $p = .002$; ($d = 0.31$). Unfortunately, due to poor signal quality, channel 4,2's results were unavailable for the "relinquisher" group. These findings are shown in Table 28.

Table 28.

Channel 4,2 – Independent samples t-tests and Cohen's d for deceptive feedback about memory accuracy

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	Relinquisher	-	-	-	-	-	-	
	Partial Relinquisher	196	1.47×10^{-8}	1.47×10^{-7}				
Pair 2	Relinquisher	-	-	-	-	-	-	
	Non-Relinquisher	196	6.54×10^{-8}	1.76×10^{-7}				
Pair 3	Partial Relinquisher	196	1.47×10^{-8}	1.47×10^{-7}	-3.10	390	.002*	0.31
	Non-Relinquisher	196	6.54×10^{-8}	1.76×10^{-7}				

For channel 5,2, there was a significant difference between participants who partially relinquished belief when given disconfirmatory feedback about memory *occurrence* ($M = -1.97 \times 10^{-7}$, $SD = 1.76 \times 10^{-7}$) and those who did not relinquish belief ($M = 1.89 \times 10^{-7}$, $SD = 7.02 \times 10^{-8}$); $t(390) = -28.56$, $p = .000$; ($d = 2.88$). Unfortunately, due to poor signal quality, channel 4,2's results were unavailable for the "relinquisher" group. These findings are shown in Table 29.

Table 29.

Channel 5,2 – Independent samples t-tests and Cohen's d for deceptive feedback about memory occurrence

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	Relinquisher	-	-	-	-	-	-	-
	Partial Relinquisher	196	-1.97×10^{-7}	1.76×10^{-7}				
Pair 2	Relinquisher	-	-	-	-	-	-	-
	Non-Relinquisher	196	1.89×10^{-7}	7.02×10^{-8}				
Pair 3	Partial Relinquisher	196	-1.97×10^{-7}	1.76×10^{-7}	-28.56	390	.000**	2.88
	Non-Relinquisher	196	1.89×10^{-7}	7.01×10^{-8}				

When looking at channel 5,2, there was a significant difference in the oxygenated hemoglobin concentration between participants who received disconfirmatory feedback about the *accuracy* of their memory and relinquished belief ($M = -9.15 \times 10^{-7}$, $SD = 2.02 \times 10^{-7}$)and those who only partially relinquished belief ($M = 1.17 \times 10^{-6}$, $SD = 1.47 \times 10^{-7}$); t(390) = -116.90, $p = .000$; ($d = 11.80$). There was a significant difference between those who relinquished belief ($M = -1.69 \times 10^{-7}$, $SD = 1.76 \times 10^{-7}$) and did not relinquish belief ($M = 5.03 \times 10^{-8}$, $SD = 4.99 \times 10^{-8}$); t(390) = -65.03, $p = .000$; ($d = 6.56$). Finally, there was also a significant difference between participants who partially relinquished belief ($M = 1.17 \times 10^{-6}$, $SD = 1.47 \times 10^{-7}$) and those who did not relinquish belief ($M = 5.03 \times 10^{-8}$, $SD = 4.99 \times 10^{-8}$); t(390) = 100.90, $p = .000$; ($d = 10.20$). These findings are shown in Table 30.

Table 30.

Channel 5,2 – Independent samples t-tests and Cohen's d for deceptive feedback about memory accuracy.

		Sample Size (n)	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pair 1	Relinquisher	196	-9.15×10^{-7}	2.02×10^{-7}	-116.90	390	.000**	11.80
	Partial Relinquisher	196	1.17×10^{-6}	1.47×10^{-7}				
Pair 2	Relinquisher	196	-9.15×10^{-7}	2.02×10^{-7}	-65.03	390	.000**	6.56
	Non-Relinquisher	196	5.03×10^{-8}	4.99×10^{-8}				
Pair 3	Partial Relinquisher	196	1.17×10^{-6}	1.47×10^{-7}	100.90	390	.000**	10.20
	Non-Relinquisher	196	5.03×10^{-8}	4.99×10^{-8}				

Using AtlasViewer GUI (Aasted et al., 2015), activation maps were generated using oxy-hemoglobin (HbO) concentration data from between 5-10 seconds of the hemodynamic response function (HRF). Figure 13 and 14 represent participants who were deemed to be "relinquishers", Figure 15 and 16 represent participants who were deemed to be "partial-relinquishers", and Figure 17 and 18 represent participants who were deemed to be "non-relinquishers".

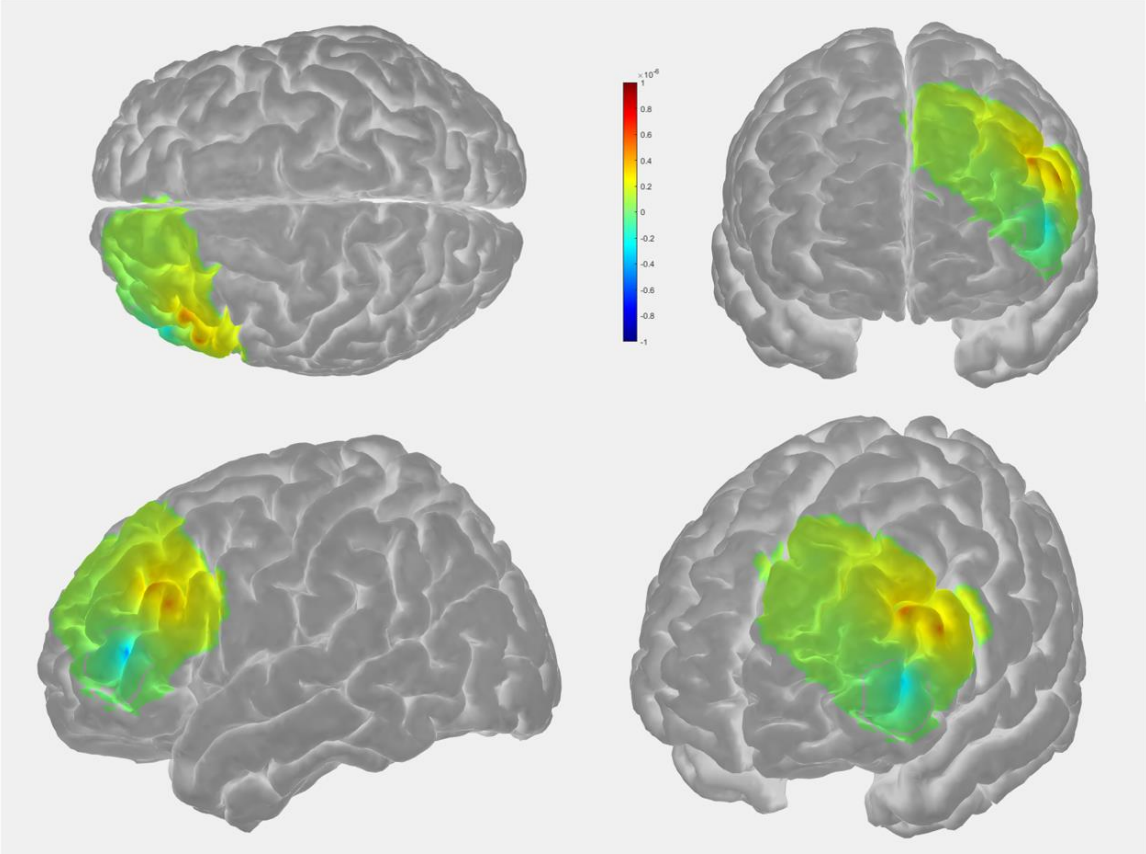

Figure 13. Participants denoted as “Relinquishers” when given disconfirmatory feedback about memory occurrence.

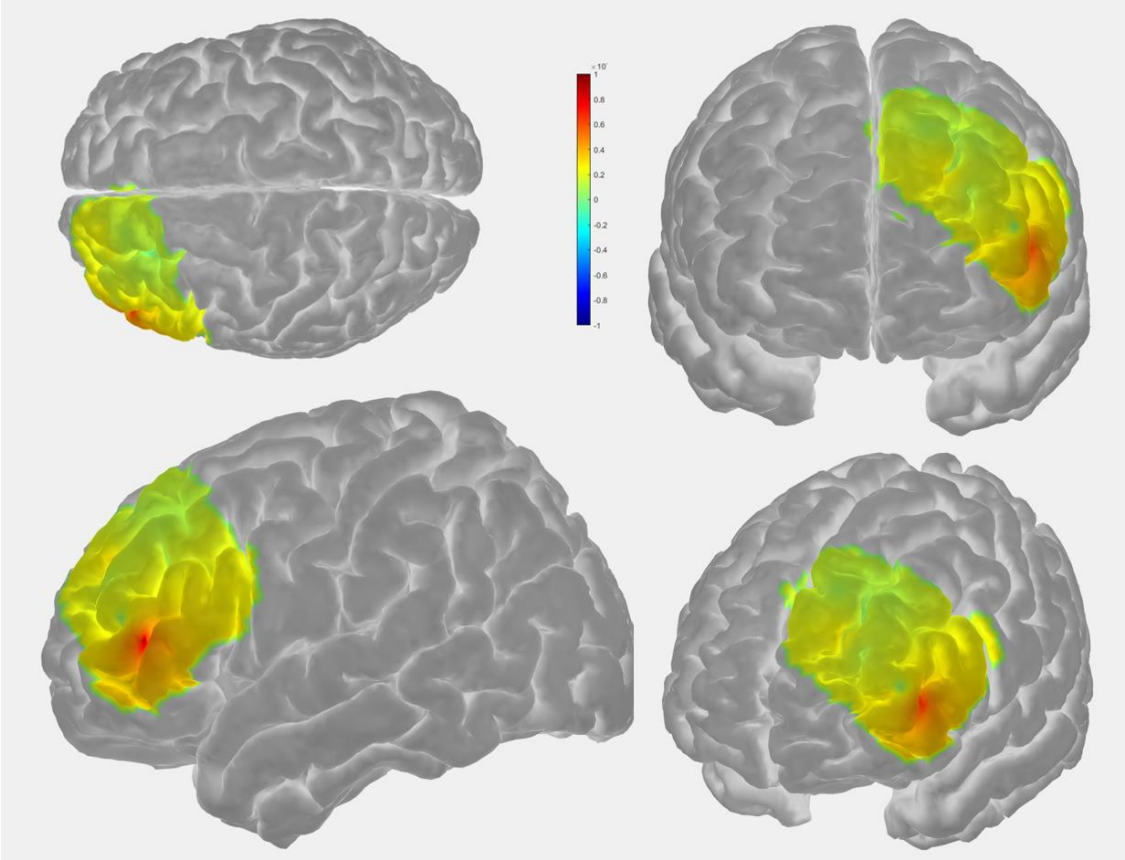

Figure 14. Participants denoted as “Relinquishers” when given disconfirmatory feedback about memory accuracy.

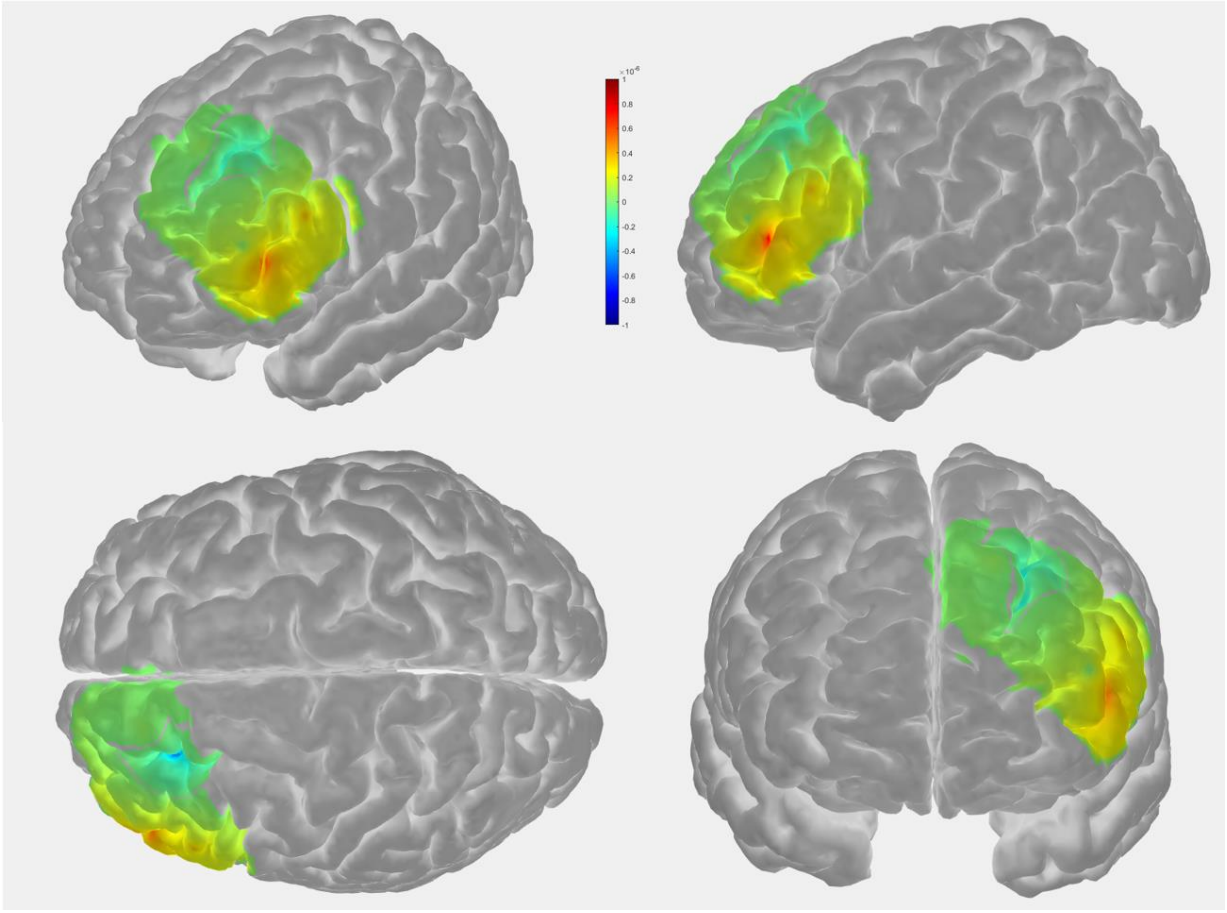

Figure 15. Participants denoted as “Partial Relinquishers” when given disconfirmatory feedback about memory occurrence.

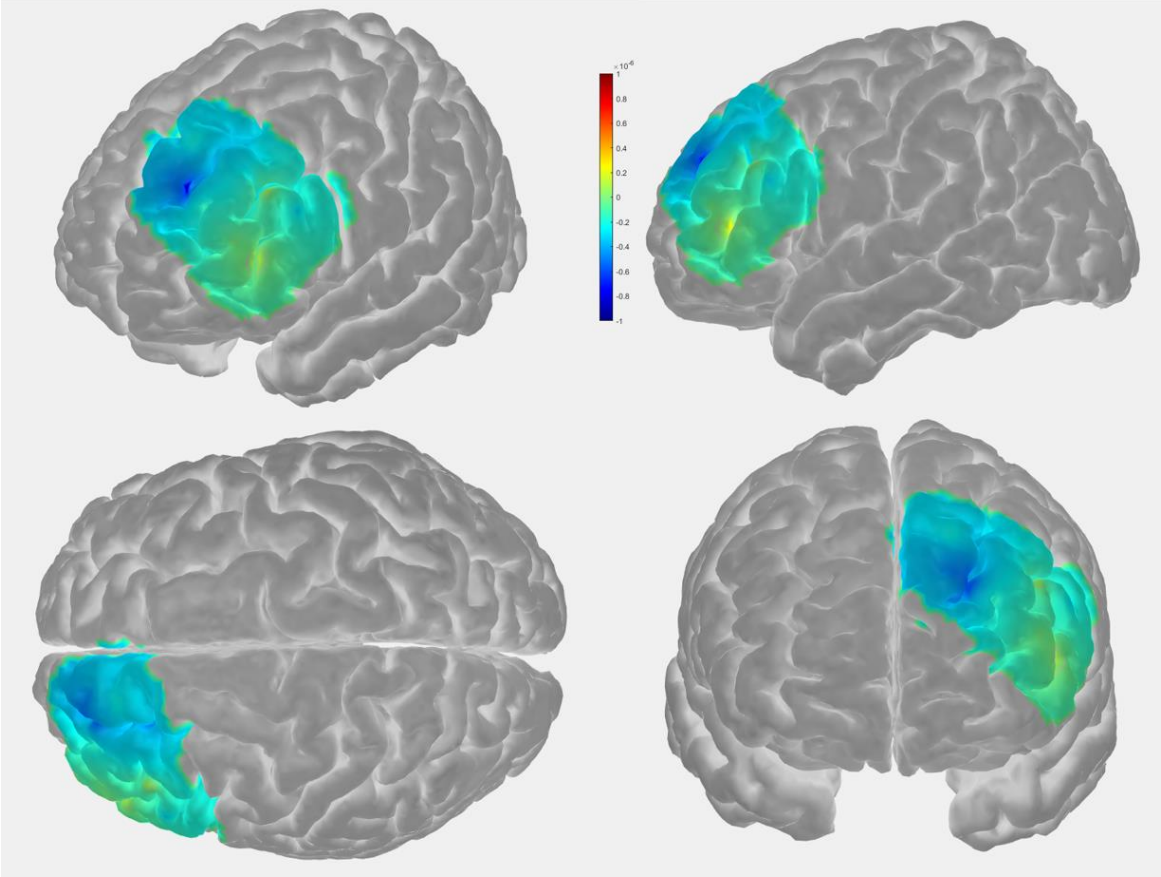

Figure 16. Participants denoted as “Partial Relinquishers” when given disconfirmatory feedback about memory accuracy.

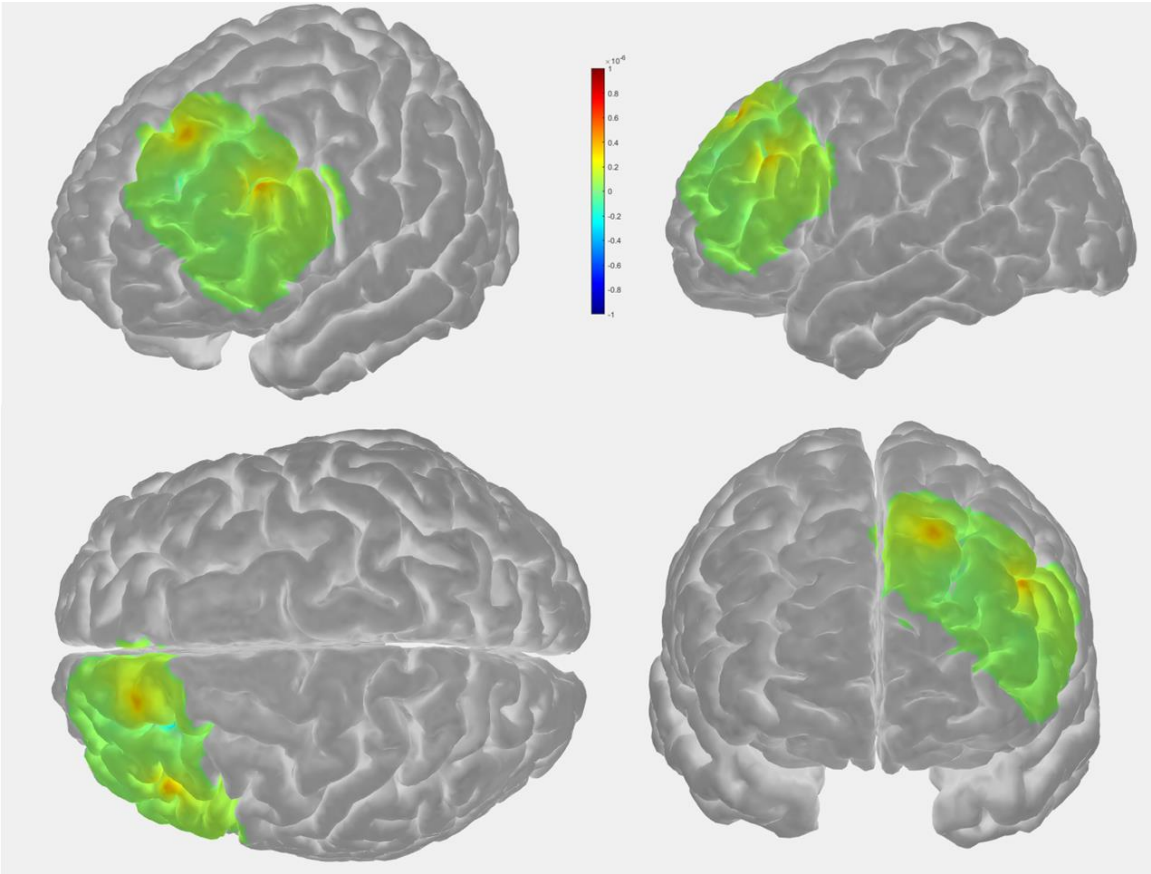

Figure 17. Participants denoted as “Non-Relinquishers” when given disconfirmatory feedback about memory occurrence.

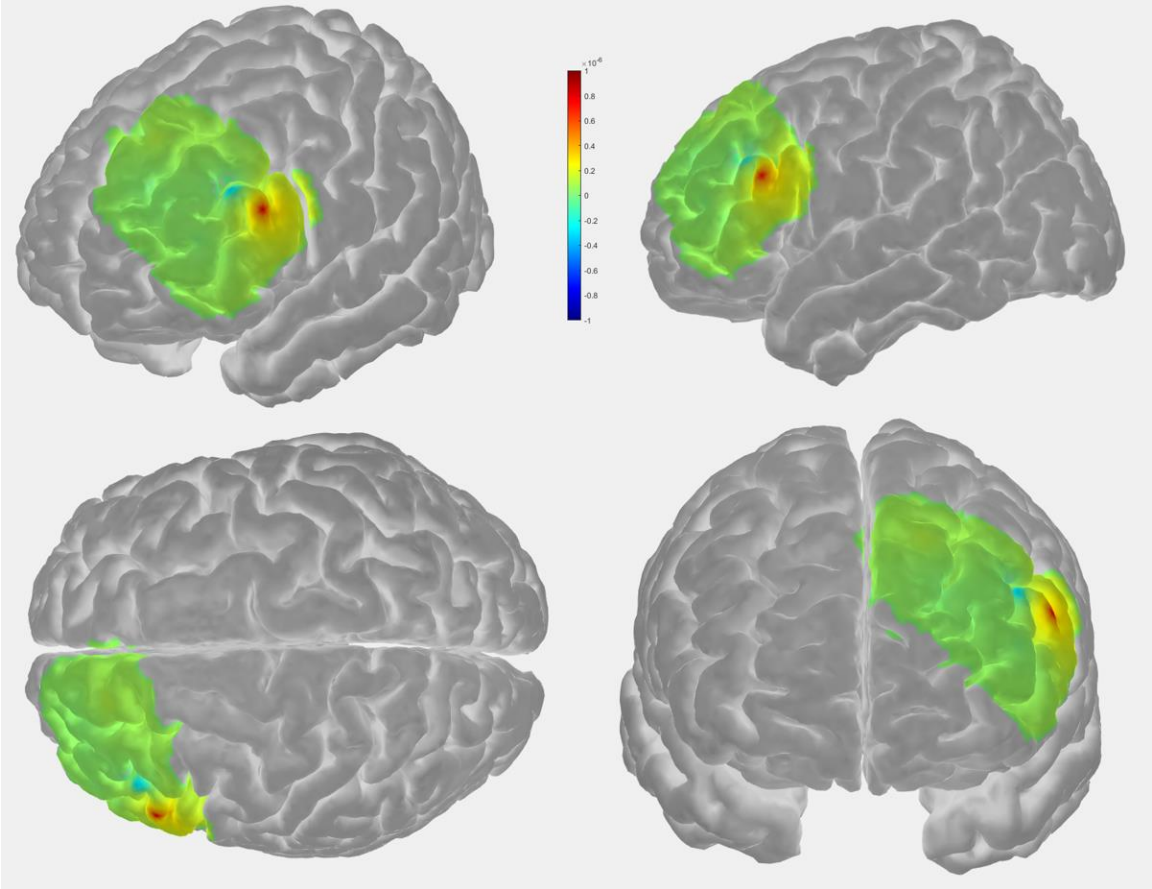

Figure 18. Participants denoted as “Non-Relinquishers” when given disconfirmatory feedback about memory accuracy.

CHAPTER FOUR

Discussion

Summary of Major Findings

The current study aimed to investigate the neurocognitive mechanisms that contribute to one's metamemorial appraisals of their memory accuracy and memory occurrence using a functional neuroimaging device. Past research has shown that despite being rated highly synonymously in laboratory settings, certain forms of questioning can create a dissociation of one's belief in accuracy and belief in occurrence appraisals, suggesting that they may in fact be distinct processes (Scoboria, Talarico, & Pascal, 2015; Korcsog, 2017; Korcsog, 2018; Korcsog et al. In Preparation). In other words, it has been shown that one can believe that their memory occurred without thinking their recollection is accurate, and one can believe that their memory is accurate, even if they no longer believe it to have occurred. Functional Near-Infrared Spectroscopy (fNIRS) is commonly utilized in studies investigating the cognitive underpinnings of human behaviour, largely because it maintains more ecological validity than other neuroimaging modalities (Pinti et al., 2018). Because of this, fNIRS was utilized within this study to measure participants' brain activity when receiving different types of social feedback about their memory.

The first research question addressed whether one's appraisals of their memory occurrence differs from their appraisals of their memory accuracy when given confirmatory or disconfirmatory social feedback from an examiner. As demonstrated by Scoboria, Talarico and Pascal (2015), Korcsog (2017), Korcsog (2018), and Korcsog et al. (2020), one's ratings of belief in accuracy and belief in occurrence can differ

dependent upon the type of feedback given. In the current study, belief in accuracy and belief in occurrence ratings dissociated when participants received disconfirmatory social feedback about memory accuracy, thus replicating the findings of Korcsog et al. (In Preparation). When looking at the functional neuroimaging findings, we see that there is a significant difference in neuronal activation across almost the entire left prefrontal cortical array (BA 8, 9, 10, and 45) when comparing all types of feedback about memory occurrence and memory accuracy. This suggests that the neurocognitive mechanisms at play are quite different when comparing one's appraisal of how accurate their memory is versus whether or not that memory occurred, regardless of whether or not that memory is deemed to be accurate or inaccurate by another person.

More specifically, when comparing the brain activity associated with one's appraisals of memory accuracy and memory occurrence qualitatively, we can see differential patterns of activation across the AtlasViewer GUI-generated activation maps (Figure 19). When participants were presented with feedback about their memory occurrence, there seems to be increased activation in the vicinity of the inferior frontal gyrus (BA 45; channel 5,2), whereas feedback about memory accuracy seemed to differ based upon whether the feedback was confirmatory or disconfirmatory. Disconfirmatory social feedback about memory accuracy showed a relative increase in activity in the inferior frontal gyrus (BA 45; channel 5,2), much like feedback about memory occurrence did. On the other hand, confirmatory social feedback about memory accuracy demonstrated increased activation in the medial prefrontal cortex (BA 8; channel 1,1).

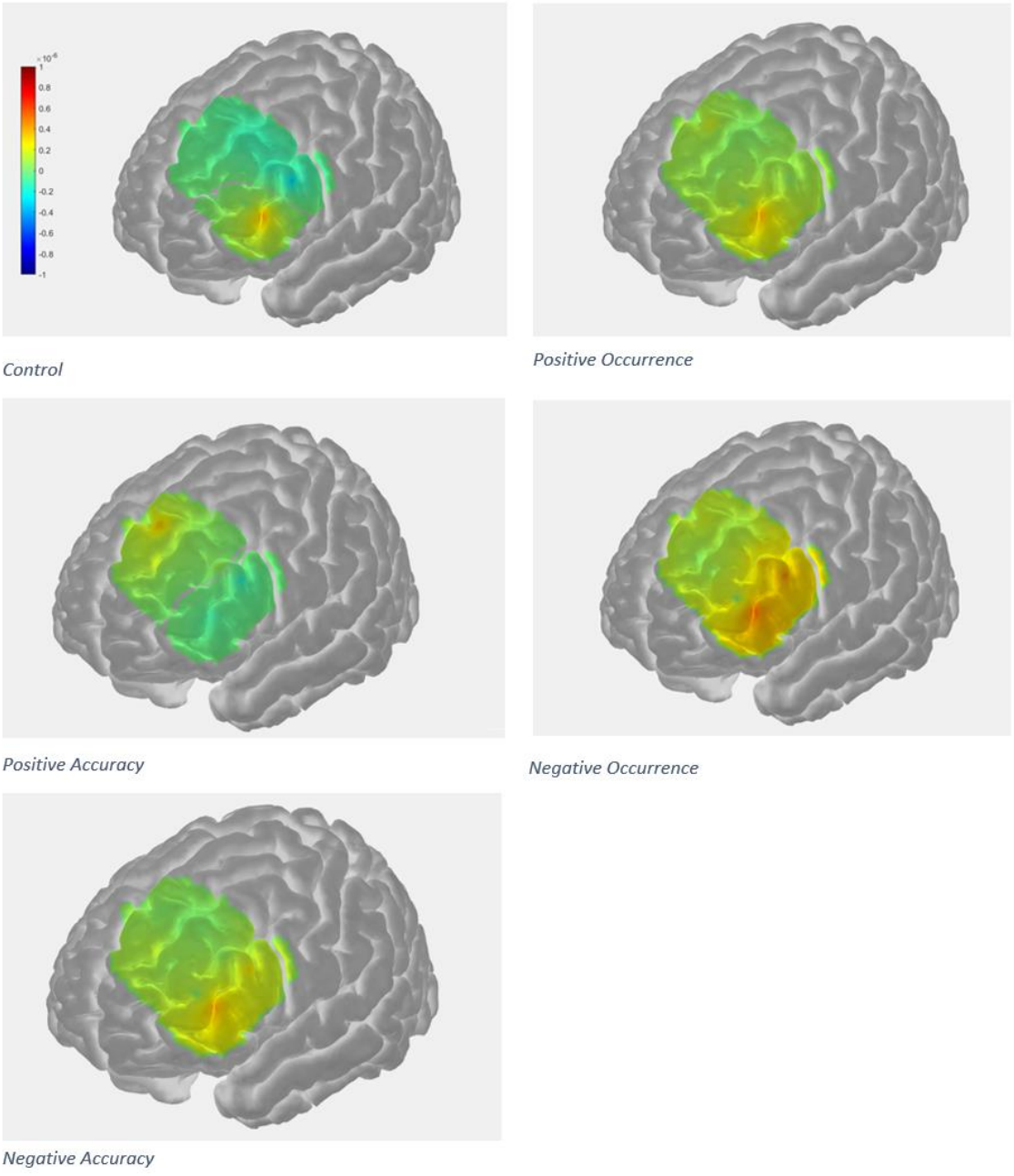

Figure 19. A comprehensive summary of the brain activity associated with each of the five feedback conditions, mapped onto a 3D brain model using AtlasViewer GUI.

The second research question aimed to further investigate the distinction between confirmatory and disconfirmatory social feedback. When participants received

confirmatory social feedback about the occurrence of a scene, their ratings of their memory accuracy and memory occurrence stayed largely the same as before they received feedback, likely due to the ceiling effects of already having rated their memory as being accurate and having occurred on the 7-point Likert-type scale. When participants received confirmatory feedback about their memory accuracy however, there was an increase in both belief in accuracy *and* belief in occurrence ratings, largely due to the fact that telling someone that they remembered the details of a scene accurately would confirm that the scene did in fact occur. Alternatively, when participants were given disconfirmatory feedback about their memory's occurrence or accuracy, a decision-making process would presumably come into play. When participants were given disconfirmatory feedback about the occurrence of their memory, both their belief in accuracy and belief in occurrence ratings significantly decreased on average. When given disconfirmatory feedback about memory accuracy, belief in accuracy ratings significantly decreased however belief in occurrence ratings did not change. Again, this is presumably due to the fact that telling someone that "they got less than 50% of the details correct" would confirm that a scene was in fact presented. However, it is notable that confirmatory feedback about memory accuracy actually increased belief in occurrence ratings, whereas confirmatory feedback about memory accuracy did not cause a significant change from pre-feedback scores.

When looking at the fNIRS findings comparing confirmatory feedback about memory occurrence to disconfirmatory feedback about memory occurrence, we see a difference in activation across nearly all of the channels. As well, when comparing confirmatory feedback about memory accuracy to disconfirmatory feedback about

memory accuracy, there is a statistical difference across nearly all of the channels. It is notable however, that channel 1,1 (BA 8; medial prefrontal cortex) did not show a difference between confirmatory and disconfirmatory feedback about accuracy, and there were small effect sizes for channels 2,1 (BA 9; dorsolateral/anterior prefrontal cortex) and 3,1 (BA 9; dorsolateral/anterior prefrontal cortex) when comparing confirmatory and disconfirmatory feedback about accuracy. As shown in Figure 19, the 3D-generated activation maps seem to show a higher concentration of oxygenated hemoglobin when participants are presented with disconfirmatory feedback about memory occurrence than when given confirmatory feedback about memory occurrence across the inferior frontal gyrus. As well, when participants were given disconfirmatory social feedback about memory accuracy, activation was greater across the inferior frontal gyrus when compared to confirmatory feedback about memory accuracy. Although the inferior frontal gyrus is largely known for its involvement in language processing and speech production, it is also thought to play a role in elaborate attentional and working memory processing such as fast and accurate responding and the elaborate processing required to increase accuracy (Tops & Boksem, 2011).Because of the variability in relinquishment patterns seen when participants received disconfirmatory social feedback in general, and in further exploration of the second research question, participants were separated into threecategories based upon their change in rating scale scores (full relinquishers, partial relinquishers, and non-relinquishers).

The level and location of activation largely differed between relinquishers, partial relinquishers, and non-relinquishers, both when given disconfirmatory feedback about memory occurrence and memory accuracy. It is notable that Cohen's d effect sizes are

very large, suggesting that there is a substantial difference in activation patterns between groups. Channel 4,2 (BA 10; anterior prefrontal cortex) was the only channel that did not show a significant difference between partial relinquishers and non-relinquishers when given disconfirmatory feedback about memory occurrence. However, this region showed a medium effect size when given disconfirmatory feedback about memory accuracy. Because there was significant variability within the "partial relinquishers" category across how they relinquished (i.e., whether they relinquished only belief in occurrence, only belief in accuracy, or if it was an unclear relinquishment pattern), results comparing this category to "relinquishers" or "non-relinquishers" should be taken with caution. A recent study by Pinti et al. (2020) explored the role of the prefrontal cortex (BA 10) in face-to-face deception using fNIRS, and found that during situations involving close personal interactions, the anterior prefrontal cortex was involved in the processing of deception. These findings differ from the current study's findings, as we tend to see less activation in the left anterior prefrontal cortex and more activation in the inferior frontal gyrus during the deceptive conditions. However, Pinti et al. (2020) used a much different deception paradigm, whereby the participants knew the task would involve lying and lie detection, rather than the current study's paradigm of being naïve to the deceptive component.

Limitations

The aim of the current study was to investigate the underlying neurocognitive mechanisms that contribute to one's appraisals of their memory. While this task was accomplished by comparing the oxygenated hemoglobin concentration in several left prefrontal cortical regions for different types of social feedback (feedback about accuracy

vs. feedback about occurrence; confirmatory feedback vs. disconfirmatory feedback), limitations to the study should be highlighted. First, with regards to the study design, it is pertinent to discuss whether watching or listening to a scene of an actress performing simple tasks and then receiving social feedback is demonstrative of social feedback for one's own autobiographical memory. While it is true that the act of a participant watching or listening to a scene and then remembering themselves being exposed to that scene is technically an autobiographical memory, targeting one's own personal memories or even scenes recorded in the first person would arguably be much more demonstrative of the cognitive processes attributed to true autobiographical memory due to the addition of an emotional and self-relevant component.

Further, another methodological limitation can be seen in the wording of the feedback given regarding memory accuracy. Telling someone that they remembered less than 50% of the details correctly leaves room for multiple interpretations such as "I remembered approximately half of the scene correctly" or "I remembered very little of the scene correctly". As well, providing this kind of feedback about memory accuracy solidifies that the scene in question did in fact occur, thus influencing belief in occurrence ratings. Following this, the "feedback" portion of the study took place in a small, dark room where the participant's brain activity was being recorded by the fNIRS machine, and there were long delays between instruction to ensure that the machine was recording the entirety of the hemodynamic response. It is possible that participants could have been clued-in to the fact that the researchers were more interested in this portion of the study, thus allowing for the deceptive component to be spoiled. This adds another limitation which is that because of the sample size after removing participants due to poor signal

strength, participants who guessed the purpose of the study when asked "what do you think we are studying today?" were not removed. However, this limitation is largely remedied by the exploratory portion of the study which separated participants based upon relinquishment type, as those participants who knew they were being deceived were either placed in the partial or non-relinquishment categories. This also draws upon the limitation of the small sample size, which did not allow for a comparison of the "partial relinquisher" sub-categories. Although the proposed sample size was met, it is recommended that future studies collect a larger sample to account for signal detection problems and individual differences in relinquishment pattern.

Apart from methodological limitations, fNIRS-specific limitations are also pertinent to this discussion. In addition to the limitations of fNIRS outlined in the introduction of this thesis, there were study-specific fNIRS limitations for this research project. First, as mentioned, the nature of an fNIRS-based study lends itself to potentially upsetting research with a deceptive component, adding an obvious indication that something important is occurring during the time of recording.

As mentioned by Pinti et al. (2019), the pre-processing pipeline across fNIRS studies is currently heterogeneous, meaning that the different filtering and functional techniques used can drastically affect the data before performing statistical analyses. This increases the probability of problems in the replicability of the study, especially when the different systems, the different software, and the different researchers at differing levels of expertise are factored in (Pfiefer et al., 2018). As well, due to the highly correlated nature of fNIRS noise data (Huppert, 2016), statistical assumptions are often violated. This problem is remediated by use of a GLM framework for statistical analysis, however

it is also up to the researcher whether or not to use the mean HRF beta coefficients produced by the linear regression analysis, or the "peak" beta coefficients produced by the linear regression analysis (as used in this study). The researcher's choice of which of the two to use can result in completely different findings.

Lastly, the use of the 10/20 system in the absence of digitizing procedures reduces the precision with which determinations about cortical location can be made. The 10/20 system has been regarded to be a tedious and error-prone procedure that involves both the manual measurement and marking of 10/20 landmarks on the head of the participant, thus making it difficult for the researcher to maintain high reliability. To address these issues, semi-automatic approaches should be used in the future, such as Xiao et al. (2017)'s proposed method. Consequently, we refrained from drawing strong conclusions about the neural representation of these processes.

Future Directions

Following the aforementioned limitations to this study, there are a few avenues pertinent for exploration in the future. First and foremost, these findings should be replicated in order to solidify the findings as reliable and valid. It would also be pertinent to increase the sample size in order to be able to parse out the difference in activation patterns of the "partial relinquishers" sub-groups.

To address the limitation of the study's scenes not reflecting one's own personal autobiographical memories, it would be interesting to conduct a study using virtual reality scenes filmed in the first-person in order to mimic the act of doing each of the tasks. This way, it would seem as though the participant themselves were performing each task, creating more personal relevance to the memory. Alternatively, obtaining

personal memories from participants' family members could be another method, however it would be much more difficult to do-so given that they would have to be unaware of this exchange.

To address the limitation of the sterility of the fNIRS testing environment, it may be helpful to set up the fNIRS at the beginning of session two rather than only during the "feedback phase". This way the entire session is deemed as being important to the study in the participant's mind, making it less obvious as to what the ultimate purpose is, and potentially maintaining the deceptive component of the study.

Implications

This line of research has increasingly strengthened the field's understanding of the distinct underlying cognitive mechanisms contributing to memory reports. By better understanding the micro-components of one's appraisals of their memory, we can more accurately capture and understand the overall implications on areas that rely heavily on memory reports such as judicial decision making, psychotherapy, and forensic interviewing. Contemporary discussions of social influences on remembering (Echterhoff & Hirst, 2009) can thus be enriched by considering what types of social feedback can influence the development and revision of event occurrence versus the sharing/editing /revision of memory for event details (see Brown et al., 2015; Foley, 2015; Scoboria, Nash & Mazzoni, 2017; and Sheen, Kemp & Rubin, 2001 for interesting examples).

Conclusion

This study was the first to investigate the neurocognitive underpinnings of one's memory appraisals when receiving different types of social feedback, and thus paves the way for the continued use of functional neuroimaging in this line of research. Left

prefrontal cortical activation patterns differed when participants were given social feedback about their memory accuracy and memory occurrence for simple scenes presented in a laboratory setting. As well, this activation differed based upon whether or not the social feedback was confirmatory or disconfirmatory/deceptive. It was also found that brain activity differed dependent on participants' decision to maintain, relinquish, or partially relinquish belief in their memory. This suggests that based upon one's pattern of brain activity when receiving social feedback, whether or not they are going to relinquish or maintain their memory could be estimated. Further, despite being rated highly synonymously in the literature and thus largely "lumped together" as one (Scoboria, Talarcio, & Pascal, 2015), findings demonstrating that belief in accuracy and belief in occurrence can be dissociated (Korcsog, 2017; Korcsog, 2018; Korcsog et al. 2020) are strengthened by this research, which concludes that belief in accuracy and belief in occurrence are neurologically distinct metamemorial appraisals and that decision-making about memory involves complex neurological processes.

REFERENCES

Aasted, C. M., Yücel, M. A., Cooper, R. J., Petkov, M. P., Boas, D. A., Cooper, R. J., Dubb, J., & Tsuzuki, D. (2015). Anatomical guidance for functional near-infrared spectroscopy: AtlasViewer tutorial. *Neurophoton, 2*(2), doi:10.1117/1.NPh.2.2.020801

Addis, D.R., McIntosh, A.R., Moscovitch, M., Crawley, A.P., & McAndrews, M.P. (2004). Characterizing spatial and temporal features of autobiographical memory retrieval networks: a partial least squares approach. *NeuroImage, 23*, 1460-1471. doi: 10.1016/j.neuroimage.2004.08.007

Arenth, P., Ricker, J., & Schultheis, M. (2007). Applications of functional near-infrared spectroscopy fNIRS to neurorehabilitation of cognitive disabilities. *Clinical Neuropsychology, 21*(1), 38–57.

Bakker, A., Smith, B., Ainslie, P., & Smith, K. (2012). *Near-infrared spectroscopy*. Applied Aspects of Ultrasonography in Humans. InTech Open Access Publisher.

Bartlett, F.C. (1932). *Remembering: A Study in Experimental and Social Psychology.* New York, NY: Cambridge University Press.

Bartocci, M., Winberg, J., Ruggiero, C., Bergqvist, L., Serra, G., & Lagercrantz, H. (2000). Activation of olfactory cortex in newborn infants after odor stimulation: a functional near-infrared spectroscopy study. *Pediatric Research, 48* (1), 18–23.

Bauernfeind, G., Wriessnegger, S. C., Daly, I., & Müller-Putz, G. R. (2014). Separating heart and brain: On the reduction of physiological noise from multichannel functional near-infrared spectroscopy (fNIRS) signals. *Journal of Neural Engineering*. https://doi.org/10.1088/1741-2560/11/5/056010

Bayley, P. J., Hopkins, R.O., & Squire, L.R. (2006). The fate of old memories after medial temporal lobe damage. *Journal of Neuroscience*, *26*(51), 13311–13317. https://doi.org/10.1523/JNEUROSCI.4262-06.2006

Blamire, A.M., Ogawa, S., Ugurbil, K., Rothman, D., McCarthy, G., Ellermann, J.M., Hyder, F., Rattner, Z., Shulman, R.G. (1992). Dynamic mapping of the human visual cortex by high-speed magnetic resonance imaging. *PNAS, 89*(22), 11069-11073. https://doi.org/10.1073/pnas.89.22.11069

Boas, D. A., Elwell, C. E., Ferrari, M., & Taga, G. (2014). Twenty years of functional near-infrared spectroscopy: Introduction for the special issue. *NeuroImage, 85*, 1–5. https://doi.org/10.1016/j.neuroimage.2013.11.033

Brazy, J.E., Lewis, D.V., Mitnick, M.H., Jöbsis van der Vliet, F.F. (1985). Noninvasive monitoring of cerebral oxygenation in preterm infants: preliminary observations. *Pediatrics, 75*(2), 217-225.

Brewer, D. D. (1995). The social structural basis of the organization of persons in memory. *Human Nature*, *6*(4), 379–403. https://doi.org/10.1007/BF02734207

Brewer, W. F. (1986). What is autobiographical memory? In D. C. Rubin (Ed.), *Autobiographical memory* (pp. 25-49). New York, NY, US: Cambridge University Press. http://dx.doi.org/10.1017/CBO9780511558313.006

Brigadoi, S., Ceccherini, L., Cutini, S., Scarpa, F., Scatturin, P., Selb, J., … Cooper, R. J. (2014). Motion artifacts in functional near-infrared spectroscopy: A comparison of motion correction techniques applied to real cognitive data. *NeuroImage, 85*, 181–191. https://doi.org/10.1016/j.neuroimage.2013.04.082

Bunce, S.C., Izzetoglu, M., Izzetoglu, K., Onaral, B., Pourrezaei, K. (2006). Functional near-infrared spectroscopy. *Institute of Electrical and Electronics Engineers: Engineering in Medicine and Biology Magazine, 25*(4), 54-62. doi: 10.1109/MEMB.2006.1657788

Ceci, S. J., & Bruck, M. (1993). Suggestibility of the child witness: A historical review and synthesis. *Psychological Bulletin, 113*(3), 403-439. http://dx.doi.org/10.1037/0033-2909.113.3.403

Cohen-Adad, J., Chapuisat, S., Doyon, J., Rossignol, S., Lina, J. M., Benali, H., et al. (2007). Activation detection in diffuse optical imaging by means of the general linear model. *Medical Image Analysis. 11*, 616–629. doi: 10.1016/j.media.2007.06.002

Conway, M.A., Turk, D.J., Miller, S.L., Logan, J., Nebes, R.D., Meltzer, C.C., Becker, J.T. (1999). A Positron Emission Tomography (PET) study of autobiographical memory retrieval. *Memory*, *7*(5-6), 679-703. doi: 10.1080/096582199387805

Conway, M. A., & Pleydell-Pearce, Christopher, W. (2000). The construction of autobiographical memories in the self-memory system. *Psychological Review*, *107*(2), 261–288. https://doi.org/http://dx.doi.org/10.1037/0033-295X.107.2.261

Cope, M., & Delpy, D. (1988). System for long-term measurement of cerebral blood and tissue oxygenation on newborn infants by near infra-red transillumination. *Medical & Biological Engineering & Computing, 26*(3), 289-294. https://doi.org/10.1007/BF02447083

Cumming, G. (2014). The new statistics: Why and how. *Psychological Science*, *25*(1), 7–29. https://doi.org/10.1177/0956797613504966

Crovitz, H. F. (1986). Loss and recovery of autobiographical memory after head injury. In D. C. Rubin (Ed.), *Autobiographical memory* (pp. 273-290). New York, NY, US: Cambridge University Press. http://dx.doi.org/10.1017/CBO9780511558313.022

D'Argembeau, A., Feyers, D., Majerus, S., Collette, F., Van der Linden, M., Maquet, P., & Salmon, E. (2008). Self-reflection across time: Cortical midline structures differentiate between present and past selves. *Social Cognitive and Affective Neuroscience*, *3*(3), 244–252. https://doi.org/10.1093/scan/nsn020

Davis, D., & Loftus, E. F. (2005). Age and functioning in the legal system: Victims, witnesses and Jurors. In Y. I. Noy & W. Karwowski (Eds.), *Handbook of human factors in litigation* (pp. 11-1 to 11-53). New York, NY: CRC Press

Delpy, D. T., & Cope, M. (1997). Quantification in tissue near-infrared spectroscopy. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *352*(1354), 649–659. https://doi.org/10.1098/rstb.1997.0046

Echterhoff, G., & Hirst, W. (2009). Social influence on memory. *Social Psychology, 40*(3), 106-110. http://dx.doi.org/10.1027/1864-9335.40.3.106

Elwell, C. E., Springett, R., Hillman, E., and Delpy, D. T. (1999). Oscillations in cerebral haemodynamics. Implications for functional activation studies. *Advances in Experimental Medicine and Biology*. *471,* 57–65.

Fantini, S. (2014). Dynamic model for the tissue concentration and oxygen saturation of hemoglobin in relation to blood volume, flow velocity, and oxygen consumption: Implications for functional neuroimaging and coherent hemodynamics

spectroscopy (CHS). *NeuroImage*, *85*, 202–221. https://doi.org/10.1016/j.neuroimage.2013.03.065

Ferrari, M., Ferrari, M., & Quaresima, V. (2007). Progress of near-infrared spectroscopy and topography for brain and muscle clinical applications. *Journal of Biomedical Optics*, *12*(6), 062104. https://doi.org/10.1117/1.2804899

Ferrari, M., & Quaresima, V. (2012). A brief review on the history of human functional near-infrared spectroscopy (fNIRS) development and fields of application. *NeuroImage*, *63*(2), 921-935. doi: 10.1016/j.neuroimage.2012.03.049.

Festinger, L. (1957). *A theory of cognitive dissonance*.: Stanford University Press.

Friston, K. J. (1994). Functional and effective connectivity in neuroimaging: A synthesis. *Human Brain Mapping*, *2*(1–2), 56–78. Retrieved from http://dx.doi.org/10.1002/hbm.460020107

Friston, K., Ashburner, J., Kiebel, S., Nichols, T., & Penny, W. (2011). *Statistical Parametric Mapping: The Analysis of Functional Brain Images*. London, UK: Academic Press.

Gabbert, F., Memon, A., & Wright, D. B. (2006). Memory conformity: Disentangling the steps towards influence during a discussion. *Psychonomic Bulletin & Review*, *13*(3), 480-485. doi: 10.3758/BF03193873

Gagnon, L., Perdue, K., Greve, D. N., Goldenholz, D., Kaskhedikar, G., and Boas, D. A. (2011). Improved recovery of the hemodynamic response in diffuse optical imaging using short optode separations and state-space modeling. *Neuroimage, 56*, 1362–1371. doi: 10.1016/j.neuroimage.2011.03.001

Gagnon, L, Yücel, M.A., Boas, D.A., & Cooper, R.J. (2014). Further improvement in reducing superficial contamination in NIRS using double short separation measurements. *Neuroimage. 85,* 127-135. doi: 10.1016/j.neuroimage.2013.01.073.

Germon, T., Kane, N., Manara, A., Nelson, R. (1994). Near-infrared spectroscopy in adults: effects of extracranial ischaemia and intracranial hypoxia on estimation of cerebral oxygenation. *British Journal of Anaesthesiology, 73*(4), 503-506.

Goel, V., & Dolan, R. J. (2004). Differential involvement of left prefrontal cortex in inductive and deductive reasoning. *Cognition, 93*(3). https://doi.org/10.1016/j.cognition.2004.03.001

Greenberg, D.L., & Rubin, D.C. (2003). The neuropsychology of autobiographical memory. *Cortex, 39*(4-5), 687-728. doi: 10.1016/S0010-9452(08)70860-8

Greenberg, D. L., Rice, H. J., Cooper, J. J., Cabeza, R., Rubin, D. C., & LaBar, K. S. (2005). Co-activation of the amygdala, hippocampus and inferior frontal gyrus during autobiographical memory retrieval. *Neuropsychologia*, *43*(5), 659–674. https://doi.org/10.1016/j.neuropsychologia.2004.09.002

Gregg, N. M., White, B. R., Zeff, B. W., Berger, A. J., and Culver, J. P. (2010). Brain specificity of diffuse optical imaging: improvements from superficial signal regression and tomography. *Frontiers of Neuroenergetics, 2*(14). doi: 10.3389/fnene.2010.00014

Gudjonsson, G.H. (2003). *The Psychology of Interrogations and Confessions: A Handbook.* Southern Gate, Chichester: John Wiley & Sons, Ltd.

Hocke, L.M., Duszynski, C.C., Debert, C.T., Dleikan, D., & Dunn, J.F. (2018). Reduced functional connectivity in adults with persistent post-concussion symptoms: A Functional Near-Infrared Spectroscopy study. *Journal of Neurotrauma, 35*(11). http://doi.org/10.1089/neu.2017.5365

Holland, A. C., & Kensinger, E. A. (2010). Emotion and autobiographical memory. *Physics of Life Reviews*, *7*(1), 88–131. https://doi.org/10.1016/j.plrev.2010.01.006

Hoshi, Y., & Tamura, M. (1993). Detection of dynamic changes in cerebral oxygenation coupled to neuronal function during mental work in man. *Neuroscience Letters. 150*(1), 5-8. doi: 10.1016/0304-3940(93)90094-2

Hoshi, Y., Tsou, B., Billock, V., Tanosaki, M., Iguchi, Y., Shimada, M., Shinba, T., Yamada, Y., & Oda, I. (2003). Spatiotemporal characteristics of hemodynamic changes in the human lateral prefrontal cortex during working memory tasks. *Neuroimage*, *20*(3), 1493–1504.

Huppert, T. J., Diamond, S. G., Franceschini, M. A., & Boas, D. A. (2009). HomER: a review of time-series analysis methods for near-infrared spectroscopy of the brain. *Applied Optics*, *48*(10), D280-D298

Huppert, T. J. (2016). Commentary on the statistical properties of noise and its implication on general linear models in functional near-infrared spectroscopy. *Neurophotonics*, *3*(1), 010401. https://doi.org/10.1117/1.nph.3.1.010401

Hyman, I.E. (1999). Creating false autobiographical memories: Why people believe their memory errors. In E. Winograd, R. Fivush, W. Hirst (Eds.), *Ecological Approaches to Cognition: Essays in Honor of Ulric Neisser* (pp. 229-248). Mahwah, NJ: Lawrence Erlbaum Associates Inc.

Hyman, I.E., Husband, T., & Billings, F. (1995). False memories of childhood experiences. *Applied Cognitive Psychology*, *9*(3), 181–197. https://doi.org/http://dx.doi.org/10.1002/acp.2350090302

ISS Medical (2016). Technical note. Retrieved from ISS website: http://www.iss.com/biomedical/instruments/imagent.html

Jacobsen, C. F. (1936). Studies of cerebral function in primates. I. The functions of the frontal association areas in monkeys. *Comparative Psychology Monographs, (13) 3,* 1-60.

Jahani, S., Fantana, A. L., Harper, D., Ellison, J. M., Boas, D. A., Forester, B. P., & Yücel, M. A. (2017). FNIRS can robustly measure brain activity during memory encoding and retrieval in healthy subjects. *Scientific Reports*, *7*(1), 1–14. https://doi.org/10.1038/s41598-017-09868-w

Karpel, M. E., Hoyer, W. J., Toglia, M. P. (2001). Accuracy and qualities of real and suggested memories: Nonspecific age differences. *Journal of Gerontology, Series B: Psychological Sciences and Social Sciences, 56*(2), 103-110. doi: 10.1093/geronb/56.2.p103

Kopelman, M. D., & Kapur, N. (2001). The loss of episodic memories in retrograde amnesia: Single-case and group studies. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *356*(1413), 1409–1421. https://doi.org/10.1098/rstb.2001.0942

Korcsog, K.H. (2017). Feedback about source and quality of recall uniquely impact occurrence and accuracy appraisals for remembered events. *Unpublished Manuscript*.

Korcsog, K.H. (2018). Providing negative feedback about the accuracy of details within scenes reduces appraisals of memory accuracy but does not affect appraisals of memory occurrence. *Electronic Theses and Dissertations*. 7533. https://scholar.uwindsor.ca/etd/7533

Korcsog, K. H., Scoboria, A., Turcas, N., Mazzoni, G., Otgaar, H., & Abeare, C. (In Preparation). Disconfirmatory social feedback about memory for actions performed in the lab elicits cognitive dissonance. *Manuscript in Preparation.*

Korcsog, K. H., Scoboria, A., & Mazzoni, G. (In Preparation). Experimentally distinguishing belief in occurrence and belief in accuracy for recorded scenes. *Manuscript in Preparation.*

Locke, D. (1971). Personal memory. In: *Memory. Problems of Philosophy*. Palgrave, London.

Loftus, E. F. (1975). Leading questions and the eyewitness report. *Cognitive Psychology, 7*(4), 560-572, http://dx.doi.org/10.1016/0010-0285(75)90023-7

Loftus, E. F. (2005). Planting misinformation in the human mind: A 30-year investigation of the malleability of memory. *Learning and Memory. 12*, 361-366, doi: 10.1101/lm.94705

Loftus, E. F., & Hoffman, H. G. (1989). Misinformation and memory: The creation of new memories. *Journal of Experimental Psychology: General, 118*(1), 100-104. doi: http://dx.doi.org/10.1037/0096-3445.118.1.100

Loftus, E. F., Levidow, B., & Duensing, S. (1992). Who remembers best? Individual differences in memory for events that occurred in a science museum. *Applied Cognitive Psychology, 6*(2), 93-107. http://dx.doi.org/10.1002/acp.2350060202

Loftus, E. F., Miller, D. G., and Burns, H. J. (1978). Semantic integration of verbal information into a visual memory. *Journal of Experimental Psychology: Human Learning and Memory, 4*(1), 19-31, doi: http://dx.doi.org/10.1037/0278-7393.4.1.19

Loftus, E. F., & Palmer, J. C. (1974). Reconstruction of automobile destruction: An example of the interaction between language and memory. *Journal of Verbal Learning and Verbal Behaviour, 13*(5), 585-589. http://dx.doi.org/10.1016/S0022-5371(74)80011-3

Matz, D. C., & Wood, W. (2005). Cognitive Dissonance in Groups: The Consequences of Disagreement. *Journal of Personality and Social Psychology, 88*(1), 22-37. http://dx.doi.org/10.1037/0022-3514.88.1.22

Mazzoni, G., Scoboria, A., & Harvey, L. (2010). Nonbelieved memories. *Psychological Science, 21*(9), 1334-1340. doi: 10.1177/0956797610379865

Merckelbach, H., Van Roermund, H., & Candel, I. (2006). Effects of collaborative recall: Denying true information is as powerful as suggesting misinformation. *Psychology, Crime & Law, 13*(6), 573-581. doi:10.1080/10683160601160679

Miller, E.K., & Cohen, J.D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24,* 167-202. doi: 10.1146/annurev.neuro.24.1.167

Milner, B., & Petrides, M. (1984). Behavioural effects of frontal-lobe lesions in man. *Trends in Neurosciences, 7*(11), 403-407. http://dx.doi.org/10.1016/S0166-2236(84)80143-5

Moscovitch, M., Cabeza, R., Winocur, G., & Nadel, L. (2016). Episodic memory and beyond: The hippocampus and neocortex in transformation. *Annual Review of Psychology, 67,* 105-134. doi: 10.1146/annurev-psych-113011-143733

Munsat, S. (1967). *The Concept of Memory.* New York, NY: Random House.

Murata, Y., Sakatani, K., Katayama, Y., Fukaya, C. (2002). Increase in focal concetration of deoxyhaemoglobin during neuronal activity in cerebral ischaemic patients. *The British Medical Journal, 73*(2), 182.

Nairne, J. S., & Pandeirada, J. N. S. (2016). Adaptive memory: The evolutionary significance of survival processing. *Perspectives on Psychological Science*, *11*(4), 496–511. https://doi.org/10.1177/1745691616635613

Neisser, U. (1996). Remembering the earthquake: Direct experience vs. hearing the news. *Memory, 11*(4), 337-358. doi: 10.1080/096582196388898

Noah, J. A., Ono, Y., Nomoto, Y., Shimada, S., Tachibana, A., Zhang, X., … Hirsch, J. (2015). fMRI Validation of fNIRS Measurements During a Naturalistic Task. *Journal of Visualized Experiments : JoVE*, (100), e52116. https://doi.org/10.3791/52116

Okado, Y., & Stark, C. E. L. (2005). Neural activity during encoding predicts false memories created by misinformation. *Learning and Memory*, *12*(1), 3–11. https://doi.org/10.1101/lm.87605

Orihuela-Espina, F., Leff, D. R., James, D. R., Darzi, A. W., & Yang, G. Z. (2010). Quality control and assurance in functional near infrared spectroscopy (fNIRS) experimentation. *Physics in Medicine and Biology, 55*, 3701–3724.

Otgaar, H., Wang, J., Franken., & Howe (2018). Believing does not equal remembering: The effects of social feedback and objective false evidence on belief in occurrence, belief in accuracy, and recollection. *Acta Psychologica, 191,* 271-280. doi: *10.1016/j.actpsy.2018.10.009*

Pfeifer, M. D., Scholkmann, F., & Labruyère, R. (2018). Signal processing in functional near-infrared spectroscopy (fNIRS): Methodological differences lead to different statistical results. *Frontiers in Human Neuroscience*, *11*(January), 1–12. https://doi.org/10.3389/fnhum.2017.00641

Pinti, P., Aichelburg, C., Gilbert, S., Hamilton, A., Hirsch, J., Burgess, P., & Tachtsidis, I. (2018). A review on the use of wearable Functional Near-Infrared Spectroscopy in naturalistic environments. *Japanese Psychological Research, 60*(4), 347-373. https://doi.org/10.1111/jpr.12206

Pinti, P., Devoto, A., Greenhalgh, I., Tachtsidis, I., Burgess, P., & Hamilton, A. (2020). The role of anterior prefrontal cortex (area 10) in face-to-face deception measured with fNIRS. *Social Cognitive and Affective Neuroscience, nsaa086.* doi: https://doi.org/10.1093/scan/nsaa086

Pinti, P., Scholkmann, F., Hamilton, A., Burgess, P., & Tachtsidis, I. (2019). Current status and issues regarding pre-processing of fNIRS neuroimaging data: An investigation of diverse signal filtering methods within a General Linear Model framework. *Frontiers in Human Neuroscience*, *12*(January), 1–21. https://doi.org/10.3389/fnhum.2018.00505

Pinti, P., Tachtsidis, I., Hamilton, A., Hirsch, J., Aichelburg, C., Gilbert, S., & Burgess, P. W. (2018). The present and future use of functional near-infrared spectroscopy

(fNIRS) for cognitive neuroscience. *Annals of the New York Academy of Sciences*, 1–25. https://doi.org/10.1111/nyas.13948

Plichta, M. M., Herrmann, M. J., Baehne, C. G., Ehlis, A.-C., Richter, M. M., Pauli, P., & Fallgatter, A. J. (2006). Event-related functional near-infrared spectroscopy (fNIRS): Are the measurements reliable? *NeuroImage, 31*(1), 116–124. doi:10.1016/j.neuroimage.2005.12.008

Plichta, M. M., Heinzel, S., Ehlis, A.-C., Pauli, P., & Fallgatter, A. J. (2007). Model-based analysis of rapid event-related functional near-infrared spectroscopy (NIRS) data: A parametric validation study. *NeuroImage, 35*(2), 625–634. doi:10.1016/j.neuroimage.2006.11.028

Rosenbloom, M. H., Schmahmann, J. D., & Price, B. H. (2012). Neuroanatomy of Decision-Making. *Journal of Neuropsychiatry and Clinical Neurosciences*, *24*(3), 266–277. https://doi.org/10.1176/appi.neuropsych.11060139

Rossi, S., Telkemeyer, S., Wartenburger, I., & Obrig, H. (2012). Shedding light on words and sentences: near-infrared spectroscopy in language research. *Brain and Language, 121*(2), 152-163. doi: 10.1016/j.bandl.2011.03.008.

Rubin, D.C. (1988). *Autobiographical Memory.* New York, NY: Cambridge University Press.

Rubin, D. C. (2006). The Basic-Systems Model of Episodic Memory. *Perspectives on Psychological Science*, *1*(4), 277–311. https://doi.org/10.1111/j.1745-6916.2006.00017.x

Saager, R., and Berger, A. (2008). Measurement of layer-like hemodynamic trends in scalp and cortex: implications for physiological baseline suppression in functional

near-infrared spectroscopy. *Journal of Biomedical Optics, 13*. doi: 10.1117/1.2940587

Scarapicchia, V., Brown, C., Mayo, C., & Gawryluk, J. R. (2017). Functional Magnetic Resonance Imaging and Functional Near-Infrared Spectroscopy: Insights from combined recording studies. *Frontiers in Human Neuroscience*, *11*(419). https://doi.org/10.3389/fnhum.2017.00419

Scholkmann, F., Kleiser, S., Metz, A. J., Zimmermann, R., Mata Pavia, J., Wolf, U., & Wolf, M. (2014). A review on continuous wave functional near-infrared spectroscopy and imaging instrumentation and methodology. *NeuroImage*, *85*, 6–27. https://doi.org/10.1016/j.neuroimage.2013.05.004

Schroeter, M.L., Bucheler, M.M., Muller, K., Uludag, K., Obrig, H., Lohmann, G., Tittgemeyer, M., Villringer, A., & von Cramon, D.Y. (2004). Towards a standard analysis for functional near-infrared imaging. *Neuroimage*, *21*, 283–290. 10.1016/j.neuroimage.2003.09.054

Scoboria, A., & Henkel, L. (2020). Defending or relinquishing belief in occurrence for remembered events that are challenged: A social-cognitive model. *Applied Cognitive Psychology,* 1-10. https://doi.org/10.1002/acp.3713.

Scoboria, A., Nash, R.A., & Mazzoni, G. (2017). Sub-types of nonbelieved memories reveal differential outcomes of challenges to memories. *Memory, 25*(7), 876-889. doi: 10.1080/09658211.2016.1203437.

Scoboria, A., Mazzoni, G., Kirsch, I., & Relyea, M. (2004). Plausibility and belief in autobiographical memory. *Applied Cognitive Psychology, 18*(7), 791-807. https://doi.org/10.1002/acp.1062

Scoboria, A., Jackson, D. L., Talarico, J., & Wysman, L. (2014). The role of belief in occurrence within autobiographical memory. *Journal of Experimental Psychology: General*, *143*(3), 1242–1258. https://doi.org/10.1037/a0034110.supp

Scoboria, A., & Talarico, J. M. (2013). Indirect cueing elicits distinct types of autobiographical event representations. *Consciousness and Cognition, 22*(4), 1495-1509. doi: http://dx.doi.org/10.1016/j.concog.2013.09.007

Scoboria, A., Talarico, J. M., & Pascal, L. (2015). Metamemory appraisals in autobiographical event recall. *Elsevier Cognition, 16*(136), 337-349. http://dx.doi.org/10.1016/j.cognition.2014.11.028

Scoville, W.B., & Milner, B. (1957). Loss of recent memory after bilateral hippocampal lesions. *Journal of Neurology, Neurosurgery, and Psychiatry. 20*(11), 11–21. https://doi.org/10.1136/jnnp-2015-311092

Sheen, M., Kemp, S., & Rubin, D. (2001). Twins dispute memory ownership: A new false memory phenomenon. *Memory & Cognition, 29*(6), 779-788.

Spreng, R. N., & Grady, C. L. (2010). Patterns of brain activity supporting autobiographical memory, prospection, and theory of mind, and their relationship to the default mode network. *Journal of Cognitive Neuroscience*, *22*(6), 1112–1123. https://doi.org/10.1162/jocn.2009.21282

Summerfield, J. J., Hassabis, D., & Maguire, E. A. (2010). Differential engagement of brain regions within a “core” network during scene construction. *Neuropsychologia*, *48*(5), 1501–1509. https://doi.org/10.1016/j.neuropsychologia.2010.01.022

Svoboda, E., McKinnon, M. C., & Levine, B. (2006). The functional neuroanatomy of autobiographical memory: A meta-analysis. *Neuropsychologia*, *44*(12), 2189–2208. https://doi.org/10.1016/j.neuropsychologia.2006.05.023

Tak, S., & Ye, J. C. (2014). Statistical analysis of fNIRS data: A comprehensive review. *NeuroImage*, *85*, 72–91. https://doi.org/10.1016/j.neuroimage.2013.06.016

Tops, M., & Boksem, M. A. S. (2011). A potential role of the inferior frontal gyrus and anterior insula in cognitive control, brain rhythms, and event-related potentials. *Frontiers in Psychology, 10.* doi: https://doi.org/10.3389/fpsyg.2011.00330

Tulving, E. (1972). Episodic and semantic memory. In: Tulving E, Donaldson W, editors. *Organization of memory.* New York, NY: Academic Press.

Tulving, E. (1983). *Elements of Episodic Memory.* New York, NY: Oxford University Press.

Tulving, E. (1985). Memory and consciousness. *Canadian Psychology/Psychologie Canadienne, 26*(1), 1-12. http://dx.doi.org/10.1037/h0080017

Van Veen, V., Krug, M.K., Schooler, J.W., Carter, C.S. (2009). Neural activity predicts attitude change in cognitive dissonance. *Nature Neuroscience*, *12*(11), 1469-1474. doi: 10.1038/nn.2413.

Vliet, F.F. (1999). Discovery of the near-infrared window into the body and the early development of near-infrared spectroscopy. doi: 10.1117/1.429952

von Lühmann, A., Li, X., Müller, K. R., Boas, D. A., & Yücel, M. A. (2020a). Improved physiological noise regression in fNIRS: A multimodal extension of the General Linear Model using temporally embedded Canonical Correlation Analysis. *NeuroImage*, *208*, 116472. https://doi.org/10.1016/j.neuroimage.2019.116472

von Lühmann, A., Ortega-Martinez, A., Boas, D. A., & Yücel, M. A. (2020b). Using the general linear model to improve performance in fNIRS single trial analysis and classification: A Perspective. *Frontiers in Human Neuroscience*, *14*(February), 1–17. https://doi.org/10.3389/fnhum.2020.00030

Wagenaar, W. A., & Crombag, H. F. (2005). *The popular policeman and other cases. Psychological perspectives on legal cases*. Amsterdam, NL: Amsterdam University Press

Wheeler, M.E., Stuss, D.T., & Tulving, E. (1997). Toward a theory of episodic memory: The frontal lobes and autonoetic consciousness. *Psychological Bulletin. 121*(3), 331–54. http://dx.doi.org/10.1037/0033-2909.121.3.331

Wright, D. B., & Livingston-Raper, D. (2002). Memory distortion and dissociation: Exploring the relationship in a non-clinical sample. *Journal of Trauma & Dissociation, 3*(3), 97-109, doi: 10.1300/J229v03n03_06

Wright, D.B., & Loftus, E.F. (1998). How misinformation alters memories. *Journal of Experimental Child Psychology, 71*(2), 155-164. https://doi.org/10.1006/jecp.1998.2467

Wright, J. C., Huston, A. C., Murphy, K. C., St. Peters, M., Pinon, M., Scantlin, R., & Kotler, J. (2001). The relations of early television viewing to school readiness and vocabulary of children from low-income families: The early 54 window project. *Child Development, 72*(5), 1347-1366. doi:10.1111/1467-8624.t01-1-00352

Xiao, X., Zhu, H., Liu, W. J., Yu, X. T., Duan, L., Li, Z., & Zhu, C. Z. (2017). Semi-automatic 10/20 identification method for MRI-free probe placement in

transcranial brain mapping techniques. *Frontiers in Neuroscience*, *11*(4). https://doi.org/10.3389/fnins.2017.00004

Ye, J. C., Tak, S., Jang, K. E., Jung, J., & Jang, J. (2009) NIRS -SPM: Statistical parametric mapping for near-infrared spectroscopy. *NeuroImage, 44,* 428-447. doi:10.1016/j.neuroimage.2008.08.036.

Yu, C. L., Chen, H. C., Yang, Z. Y., & Chou, T. L. (2020). Multi-time-point analysis: A time course analysis with functional near-infrared spectroscopy. *Behavior Research Methods*. https://doi.org/10.3758/s13428-019-01344-9

Yücel, M. A., Selb, J., Aasted, C. M., Lin, P. Y., Borsook, D., Becerra, L., et al. (2016). Mayer waves reduce the accuracy of estimated hemodynamic response functions in functional near-infrared spectroscopy. *Biomedical Optics Express, 7,* 3078–3088. doi: 10.1364/BOE.7.003078

Yücel, M. A., Selb, J. J., Huppert, T. J., Franceschini, M. A., & Boas, D. A. (2017). Functional Near Infrared Spectroscopy: Enabling Routine Functional Brain Imaging. *Current Opinions in Biomedicine and Engineering*, *4*, 78–86. https://doi.org/10.1016/j.cobme.2017.09.011

Zaragoza, M.S., & Lane, S.M. (1994). Source misattributions and the suggestibility of eyewitness memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*(4), 934-945. doi: http://dx.doi.org/10.1037/0278-7393.20.4.934

Zhang, Q., Brown, E. N., and Strangman, G. E. (2007). adaptive filtering for global interference cancellation and real-time recovery of evoked brain activity: a monte carlo simulation study. *Journal of Biomedical Optics, 12*. doi: 10.1117/1.2754714

APPENDICES

Appendix A: Belief in Occurrence and Belief in Accuracy Rating Items

Belief in Occurrence

1. How likely is it that this scene was presented?

   (1 Definitely did not view; 7 Definitely viewed)

2. It is true that this scene was presented.

   (1 Not at all true; 7 Completely true)

Belief in Accuracy

3. How confident are you that your memory for this scene is accurate?

   (1 Not at all confident; 7 Completely confident)

4. What proportion of your memory for this scene is accurate?

   (1 Not at all accurate; 7 100% accurate)

Appendix B: List of Presented Scenes

1. A girl making a sandwich
2. A girl washing her hands
3. A girl painting a picture
4. A girl styling a doll's hair
5. A girl painting someone's nails
6. A girl doing a puzzle
7. A girl placing numbers in a foam board.
8. A girl doing laundry
9. A girl mixing liquids
10. A girl picking a flower
11. A girl sealing a letter to mail it
12. A girl writing the numbers 0-10 on a piece of paper
13. A girl blowing up a balloon
14. A girl opening a present
15. A girl putting on makeup
16. A girl stretching
17. A girl brushing her teeth
18. A girl making a coffee
19. A girl dressing a doll
20. A girl eating dinner
21. A girl making something out of clay
22. A girl chewing bubble-gum
23. A girl doing math problems
24. A girl doing exercises
25. A girl lighting candles
26. A girl washing her face
27. A girl dealing playing cards
28. A girl colouring in a colouring book
29. A girl setting the table
30. A girl fixing a remote control
31. A girl writing in a card
32. A girl doing a craft
33. A girl painting Christmas ornaments
34. A girl cutting a snowflake out of paper
35. A girl making a paper airplane
36. A girl sorting coins
37. A girl flipping through a textbook
38. A girl putting tape on a bird house
39. A girl bowling
40. A girl putting on a rollerblade
41. A girl brushing and braiding her hair
42. A girl making a salad
43. A girl making an ice cream sundae
44. A girl sealing a letter to mail it
45. A girl dancing
46. A girl throwing a toy for her dog
47. A girl kicking a soccer ball
48. A girl making a phone call
49. A girl making her bed
50. A girl bouncing on a trampoline
51. A girl making batter for a cake
52. A girl placing coloured beads on to a string
53. A girl drawing on a pumpkin
54. A girl placing coloured circular stickers on paper
55. A girl drawing a rainbow
56. A girl making a dog do a trick
57. A girl making tea
58. A girl doing dishes
59. A girl doing a cartwheel
60. A girl hitting a baseball with a bat

Appendix C: List of Scenes that Were Not Presented

1. A girl cutting her nails
2. A girl organizing her pencil case
3. A girl playing games on an iPad
4. A girl brushing a kitten
5. A girl washing a car
6. A girl sewing fabric
7. A girl planting a flower in a garden
8. A girl making a gingerbread house
9. A girl flossing her teeth
10. A girl drawing a family portrait
11. A girl flying a kite
12. A girl making a pillow fort
13. A girl playing the piano
14. A girl munching on cookies
15. A girl opening and closing a window
16. A girl cleaning the bathroom sink
17. A girl playing a board game
18. A girl pumping air into the tires of her bike
19. A girl diving into a swimming pool
20. A girl stapling paper together
21. A girl studying for a test
22. A girl playing bingo
23. A girl writing her name 3 times
24. A girl tracing her hand on a piece of paper
25. A girl printing out pictures from a printer
26. A girl sharpening a pencil and writing with it
27. A girl using a calculator to solve a math problem
28. A girl hammering a nail into a piece of wood
29. A girl washing her windows with a squeegee
30. A girl putting on a sweater

Appendix D: Participant Pool Advertisement

Title: Remembering Recorded Events

Duration: 2 hours

Bonus points: 3

Description: If you volunteer to participate in this study, we will ask you to come to the lab and watch or listen to simple scenes (such as “making a sandwich”). One week later, we will ask you will complete a test of your memory for these scenes while your brain activity is being recorded using Functional Near-Infrared Spectroscopy (fNIRS). Both the first and second session will take 60 minutes to complete, for a total of no more than two hours of your time. Participants with auditory or visual impairments will not be able to participate. The second part of the study will take place in a small enclosed lab space, and we ask participants to provide access to scalp and skin. Participants are unable to wear light-absorbent makeup, hair coverings, or wigs.

Appendix E: Post-Study Debriefing

So that was the last question I had for you. Now I'm just going to tell you a little bit more about the study.

First of all, thank you for participating. This study is examining how people make decisions about their memories for past events. While we might be tempted to think of our memories as fixed in our minds, research has shown that memories are continuously being influenced by new information and experiences that we have. This has led some researchers to study how people make decisions about memories when they encounter different types of information.

In this study, we were interested in seeing what people do when feedback is given that the accuracy or occurrence of their memories are incorrect. In this study there were two phases. First, you studied many different simple scenes – some you watched and some you heard.

The second phase, the memory test, occurred today. You may recall that after you completed the memory test there were a few times that I gave you feedback that your memory was incorrect. For some of the memory test items, your memory may have been incorrect – you might have missed key details within scenes, or included details that were not actually there in your descriptions. You also may have said that a scene was presented when it was not, or said that a scene was not presented when it was. However, the feedback I gave you that your memory was incorrect during the second phase (when you were being recorded with the fNIRS) today was false. We are interested in seeing how people react to feedback that strong memories are incorrect. In this study, we were specifically examining how often people reject versus how often they accept the feedback, and how your brain activity differs dependent on the type of social feedback you received. The Functional Near-Infrared Spectroscopy allows us to be able to do just that, by measuring changes in blood flow in your brain.

So, there was a type of deception in this research. For a small number of scenes that you correctly identified as being seen, the feedback that I gave you was incorrect. Those scenes were ***name scenes given feedback condition 3 or 4.*** We apologize for the need for the deception, but there really is no way to study how people respond to feedback from others without sometimes contradicting accurate memories. With that being said, it is important to note that this study was not measuring memory accuracy, nor does susceptibility to social feedback or challenges tell us anything about your memory ability.

Now that you know about the study, do you consent to the use of your data? Do you have any questions, or anything else that you would like to tell us about what it was like for you to participate in this study?

Thank you again for participating. [Arrange compensation; crediting of bonus points].

Appendix F: Transcribed Example of Audio Description

"So, there was a woman standing in a kitchen and she had a piece of bread and she was cutting it with a knife. Um, and then she uh, she had to pull it apart. A-and it wasn't like totally even. And then uh, she had some stuff she was putting on it. So, I think there was meat and cheese, and then she had condiments so there was some ketchup. And, uh that was it. She made a sandwich."

Appendix G: Consent Form

CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: Remembering Recorded Events

You are asked to participate in a research study conducted by Kassandra Korcsog and Dr. Chris Abeare, Department of Psychology, University of Windsor. If you have any questions or concerns about the research, please feel to contact Kassandra Korcsog korcsog@uwindsor.ca or Dr. Abeare at cabeare@uwindsor.ca. This study is being conducted to satisfy the requirements of Kassandra Korcsog's Master's thesis.

PURPOSE OF THE STUDY

The purpose of this study is to examine aspects of memory for recorded scenes, and associated neurology using Functional Near-Infrared Spectroscopy (fNIRS), a safe, non-invasive method of recording blood flow in the brain via infrared light that is shone through the skull and then detected. This is similar to shining a flashlight through one's hand.

PROCEDURE

If you volunteer to participate in this study, we will ask you to watch or listen to a series of recorded scenes (e.g. an actor making a sandwich). One week later, you will complete a memory test. This session will be audio recorded and your brain activity will be measured using Functional Near-Infrared Spectroscopy (fNIRS). The first session will take 60 minutes to complete, and the second session will take 60 minutes, for a total of no more than 120 minutes (2 hours) of your time. The fNIRS will be used during the second session to record brain activity while you are being asked questions about your memory for the scenes presented in session one. The study will take place in a small, enclosed lab setting. You will not be contacted for any follow-up sessions related to this study.

POTENTIAL RISKS AND DISCOMFORTS

There are no known risks from participating in this study. On rare occasion people may experience mild emotional discomfort or mental fatigue during some of the tasks, but any negative reactions are expected to be mild and temporary. You will be wearing a neoprene headband that is used to measure brain activation. fNIRS is safe to use, however, the device uses class 2/3R lasers which can be harmful to one's eyes if mishandled. The researcher has certified training to handle the device and will give you clear, explicit instructions before the device is switched on. To set up the headband, the researchers will have to touch your head and hair. You will be asked to sit as still as possible while wearing the headband. Some people may feel discomfort from the headband or from sitting in one position for an extended period. It is possible that some people may experience mild and transient anxiety, as the testing takes place in a small room with reduced lighting. If you feel uncomfortable answering any questions or performing any tasks, you can choose to discontinue that section of the study without penalty. If you feel the need to talk to anyone about your feelings or wish to seek assistance, you will be provided a list of resources you can contact in the letter of explanation, at the end of the study.

POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY

There is no direct benefit to participating in this study. However, the information gained from the overall study may contribute to research around memory**.** You can also learn about optical imaging and attention. When the session is over, the purpose and hypotheses of the study will be described in more detail.

COMPENSATION FOR PARTICIPATION

We will provide you with 3 bonus points on completion of the study, if you are enrolled in the Psychology Participant Pool and an eligible course. 2 points are for completion of the study (Part 1: scene presentation (1

point) and Part 2: memory test (1 points), separated by one week). An extra 0.5 points will be given after the commencement of each week, for a total of 3 bonus points.

CONFIDENTIALITY

We guarantee that your participation in this study will be confidential. We will not reveal to anyone else that you took part in the study without your permission. Any information that can be identified with you will be stored securely in Dr. Abeare's laboratory. On the completion of the study, any information identified with you will be removed from the study record. The audio recording will be stored securely, transcribed, and deleted on the completion of the study. After the study ends, a record of the bonus points will be kept for one year, at which time it will be destroyed. All de-identified data will be retained indefinitely.

PARTICIPATION AND WITHDRAWAL

During the duration of your study appointment, you may withdraw without penalty. If you indicate that you would like to withdraw, we will ask if you are willing to explain why; you are not obligated to tell us your reason for withdrawing. The investigator may withdraw you from this research if circumstances arise which warrant doing so. You will receive 0.5 bonus points per half hour of time that you have spent in the study up to the time of withdrawal. Participant data can only be withdrawn up to 10 days after the completion of their study appointment.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE PARTICIPANTS

The results of the study will be posted to the University of Windsor REB website by August 2020 **(https://scholar.uwindsor.ca/research-result-summaries/).**

SUBSEQUENT USE OF DATA

These data may be used in subsequent studies, in publications and in presentations.

RIGHTS OF RESEARCH PARTICIPANTS

If you have questions regarding your rights as a research participant, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

SIGNATURE OF RESEARCH PARTICIPANT/LEGAL REPRESENTATIVE

I understand the information provided for the study Remembering Recorded Events as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

_____

Name of Participant

_____ _____

Signature of Participant Date

SIGNATURE OF INVESTIGATOR. These are the terms under which I will conduct research.

Signature: _____ Date: _____

VITA AUCTORIS

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